U. S. DEPARTMENT OF AGRICULTURE,
BUREAU OF CHEMISTRY—BULLETIN NO. 79.
H. W. WILEY, Chief of Bureau.

THE TESTING OF ROAD MATERIALS,

INCLUDING THE METHODS USED AND THE RESULTS OBTAINED IN THE ROAD MATERIAL LABORATORY,

IN COLLABORATION WITH THE OFFICE OF PUBLIC-ROAD INQUIRIES.

BY

LOGAN WALLER PAGE,
Chief, Road Material Laboratory,

WITH THE COOPERATION OF

ALLERTON S. CUSHMAN,
Chemist, Road Material Laboratory.

WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Bureau of Chemistry,
Washington, D. C., July 20, 1903.

Sir: I have the honor to transmit herewith for your approval a manuscript embodying the results of the tests conducted in the Road Material Laboratory of this Bureau since its establishment by you in October, 1900, together with an exposition of the methods used in obtaining these results, and to recommend that this report be published as Bulletin 79 of the Bureau of Chemistry. I beg to make acknowledgment of the cordial cooperation of the Office of Public-Road Inquiries in these investigations, without which this work could not have been done.

The illustrations, which comprise five half-tone photos and ten text figures, are regarded as necessary to a clear understanding of the text.

Respectfully,

H. W. Wiley,
Chief.

Hon. James Wilson,
Secretary of Agriculture.

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THE TESTING OF ROAD MATERIALS.

INTRODUCTION.

The Road Material Laboratory was established by the Secretary of Agriculture in December, 1900. Work was not begun, however, until several months later on account of the time necessary to effect its equipment. The fiscal year ended June 30, 1902, was the first year of its operation. The laboratory at present contains all the necessary appliances for making tests on road materials and for investigating some of the more important problems connected with the work.

The main object of this bulletin is to describe in some detail the methods and work of the laboratory and to give the results obtained up to the present time. Incidentally, the physical, mechanical, and chemical agencies which act upon road materials are discussed and a brief history of the testing of such materials is given.

The Road Material Laboratory tests road materials, without charge, for citizens of the United States and reports to them the information obtained. In addition to routine tests on samples submitted, investigations are conducted for the improvement of road materials. The laboratory is prepared to test rocks, gravels, and clays for road construction, tiling, cement and concrete, and paving blocks of stone, brick, wood, asphalt, and bituminous matter. The principal activities may be classified under the following heads:

(1) Tests for determining the quality of materials to aid road builders in selecting those most suitable for their work.

(2) The investigation of various processes to develop simple, appropriate, and reliable tests.

(3) The collection of data for use in drawing up specifications for standards of quality.

(4) Scientific research to develop new materials or mixtures, and the study of problems which may arise in road building.

The most important work comes under the first head, for the main object of the laboratory is to obtain results, by means of appropriate tests on small samples, which will agree sufficiently well with the results of practice to aid the road builder in selecting the most suitable materials from those available for his work. That the laboratory may serve its purpose, the tests adopted must be of such a nature that they can be executed with dispatch, and the results should be clear and comprehensive. While it is necessary that the results should indicate the wearing qualities of the materials in service, it is unnecessary, as well as impracticable, that an attempt should be made to imitate the exact conditions of service. Laboratory experiments have been designed in various ways to reproduce the conditions that obtain in practice, but they have failed for the obvious reason that the principal element in such conditions is lapse of time, which renders quick results impossible.

It is apparent that no single material or class of materials will suit all conditions of climate and traffic. To get the best results it is necessary that the materials selected, as well as the methods of construction, should be adapted to the special conditions of the road that is to be built or maintained. This is not always practicable and is often impossible. Much can be done, however, by means of laboratory tests to determine which of the available materials is best suited for use, and this work constitutes the chief usefulness of the Road Material Laboratory. A macadam road, when properly constructed, costs from $4,000 to $10,000 a mile, and the cost of many other types of road are greatly in excess of this. An error in the selection of a material means an inferior road and occasionally complete failure. Such an error, therefore, may cause a great loss of money to the community in which it occurs.

No explanation is necessary of the second and third subdivisions of the work, i. e., the development of new tests and the collection of correlated data, which is similar in most respects to that of all testing laboratories.

The fourth subdivision or research work, including the development of new materials, is of a most important character. New road materials are occasionally developed, and the methods for using old ones are constantly improving. It is most important to test and investigate such materials and methods if the best results are to be derived from them. Practically none of our rural towns or counties has the facilities or means to carry on such investigations, and it is in these districts that better roads are most needed. Even when road building is attempted materials and methods are frequently used which are unsuited to the conditions of climate and traffic and the result is failure.

Probably the most difficult problem to solve for the betterment of rural highways, and one on which the Road Material Laboratory has been at work for some time, exists in those sections of our country where no hard materials are to be found from which roads can be constructed. Many of these districts are of very great extent, and have only a clay soil on which and from which to build roads. The result is that during a considerable portion of the year the roads are almost impassable and are rarely good at any time. The Road Material

Laboratory has carefully studied the methods of burning clay for ballast in use by a number of western railroads. By somewhat modifying these methods very satisfactory roads can undoubtedly be made at a moderate cost in districts where the clay is of a suitable nature. Experiments are also being made with mixtures of crude petroleum and asphaltum which give promise of good results.

Before taking up any of the above subjects in detail it will be well to consider first some of the important physical and mechanical properties of road materials, and also some of the principal agents in the destruction of roads.

IMPORTANT PHYSICAL AND MECHANICAL PROPERTIES OF ROAD MATERIALS.

There are three chief properties essential to good road materials, and only these will be considered here. They are hardness, toughness, and cementing or binding power. Although these properties, at least hardness and toughness, have long been recognized by those familiar with the subject, yet they have never been properly defined and the terms have been very much confused. This is not at all surprising, for hardness and toughness are closely related. It would be well, therefore, to define these terms from the road maker's standpoint before going further.

HARDNESS.

There is no widely accepted measure of the property of hardness. Even in the case of metals, the hardness of which has received much study, there are many tests based on different conceptions of the term. The many methods devised for measuring hardness may be summarized under the following heads: Drawing substance under a point;[a] drawing a point over substance and determining resistance;[b] grooving with a standard edge and determining the depth of groove;[c] boring substance with a standard point and ascertaining depth of hole and number of revolutions;[d] grinding with a standard powder and taking the loss inversely;[e] compressing lenses on plates of substance and taking as the hardness the limit of pressure per unit of surface multiplied by the cube root of the radius of curvature;[f] compressing a point into substance and taking the volume of indentation inversely.[g]

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[a] Pekarek, Sitz. v. k. k. Akad. Wien, 1854, vol. 13. (Contains complete biography of earlier papers.)

[b] Turner, Proceedings Phil. Society, Birmingham, 1886.

[c] Pfaff, Sitz. k. k. Bayer. Akad., 1883.

[d] Pfaff, ibid., 1884.

[e] Rosiwal, Verhandl. k. k. Geol. Reichsanstalt, 1896, **17**: 475.

[f] Auberbach, Wied. Ann., 1891–96.

[g] Report of Experiments on Metal for Cannon, United States Ordnance Department, 1856.

All of these tests were designed for substances of a homogeneous nature, and are consequently not at all suited to any of the road materials. Further than this, it can be seen that in their conception of hardness some of the investigators differ greatly. All of these methods, as well as modifications of them, are based either on abrasion or penetration.

The varying demands of technology give rise to different definitions and methods of testing, and the method used in any particular case must give a measure of the value of a new material for the purpose for which it is intended. To permanently deform a substance by compression with a pointed or spherical instrument tests altogether different properties from those opposed to abrasion.

Only one test has yet been devised for determining the hardness of road materials, and that, the writer believes, gives the value of this property as understood by road builders in a satisfactory manner. This is the Dorry test of the French School of Roads and Bridges which consists in grinding specimens with sand of a standard size and quality. This method of grinding with a powder has the advantage of having been used as a test for hardness by a number of the most able students of the subject, and at the same time valuable results have been obtained from it on the very class of materials in which we are most interested. Hardness, therefore, will be defined as the resistance which a material offers to the displacement of its particles by friction. The measure of hardness will be, inversely, as the loss of weight arising from the scoring by an abrasive agent.

TOUGHNESS.

In the consideration of road materials toughness is understood to mean the power possessed by a material to resist fracture under impact. As the surface of a road is continually subjected to the pounding of traffic, it can be seen that toughness is an important property from the standpoint of the road builder. From the laboratory standpoint the problem is not altogether a simple one, and considerable difficulty has been found in designing a suitable test for measuring the degree to which a road material possesses this property.

With homogeneous, structureless, brittle materials, resistance to impact may be due to a relatively low modulus of elasticity combined with high elastic limit. Provided a blow is delivered by a flat striking head with small local damage, on such a material toughness will be almost wholly due to elasticity. In this case there will be a critical energy of blow below which the specimen under test will not be broken by an indefinite number of blows, and in excess of which it will be broken by a single blow. The toughness of a road material in this instance will vary directly as the square of the elastic limit, which equals the ultimate strength, and inversely as the modulus of elasticity. In testing such materials under impact it would be necessary to apply a number of blows of successively increasing energy, and note that blow which causes failure. A test involving this principal will be described further on in detail.

With heterogeneous materials like most of the rocks used in road building, toughness depends on a number of factors. Among these may be mentioned interlocking of the crystals, the nature of the crystals themselves, and in some cases the nature of the cementing or binding agent. This matter has received but little study.

There is another class of road materials whose toughness is due to a combination of properties not considered under the above definition. It includes those materials capable of considerable deformation without rupture when stressed beyond the elastic limit. Asphaltum and tar practically constitute this class. They distinctly come under the head of tough substances; but it is obvious that toughness in this sense is viscosity and malleability.

CEMENTING OR BINDING POWER.

The binding power or, as it has now come to be called, the cementing value of a road material is the property possessed by rock dust or other finely divided material found in nature to act as a cement on the coarser fragments composing crushed stone or gravel roads. This property varies enormously, not only with different kinds of rocks, but also with those which are practically identical in classification and chemical composition. The absence of cementing power is so pronounced in some varieties of rock that they can never be made to compact with the road roller or under traffic. As the binder surface of a macadam or gravel road is most exposed to the action of wind and rain, as well as the wear and tear of traffic, it can be seen that the presence of this property is most essential to good results. Further than this, the hardness and toughness of the binder surface, more than of the rock itself, constitutes the hardness and toughness of the road, for if a load be sufficient to destroy the bond of cementation of the upper surface of a road, the stones below are soon loosened and forced out of place. The impervious shell obtained by the use of a rock of high cementing value gives the greatest protection to the foundation of a road. Moreover, it is a matter of common observation that a good surface which binds well is less dusty and less muddy, while the advantage from the standpoint of economy is very great, as it is only the loose, unbound material which is ordinarily carried away by wind and water.

In view, therefore, of the importance of this property, it has been made the subject of especial study in this laboratory. It was most important to know the cause of the cementing value in order to determine what could be done to improve the conditions of service. The results of this study, which have already been published as a contribution from the Bureau of Chemistry, have been very satisfactory.[a]

It appears that the cementing value depends upon a certain hydrated colloid condition of the particles, or some proportion of the particles. All rock powders that cement well are hydrated, i. e., contain water of combination, although it does not follow that all hydrated rock powders will cement. It seems that only a certain kind of water of combination is concerned with and measures the cementing value. This property is undoubtedly related to that of plasticity in clays, and, in a few words, is due to amorphous, inorganic particles which by reason of their characteristic porous structure are able to absorb and hold water, thereupon assuming a plastic and coherent condition. Heating above a certain temperature destroys this structure, and the powder no longer possesses the slightest cementing value. It is probable that this theoretical investigation will lead to important practical developments.

Under the head of physical tests will be found a description of the methods, as used in this laboratory, for testing the cementing power of road materials, in Table III, page 33, are given the maximum and minimum results obtained on various kinds of rock, and in Table A of the Appendix the individual results on each sample.

THE CAUSES OF THE DETERIORATION OF ROADS.

The agencies to be discussed as tending to the deterioration of roads include traffic (pounding of horses' feet, action of wheels, effect of load), weathering or chemical decomposition, frost, wind, and water, and may be classified as mechanical, chemical, and physical agencies.

MECHANICAL AGENCIES.

The severe pounding to which a road is subjected by the action of horses' feet tends to destroy the binding surface and loosen the underlying stones. The fine material when loosened is more readily carried off by wind or rain and water can then more readily penetrate to the foundation. The properties necessary to resist this action are, with stone blocks or brick pavements, high resistance to impact, and with crushed stone and gravel, binding or cementing power in the fine material of the surface and toughness in the larger fragments.

The effect produced on roads by the wheels of vehicles varies much with the material of which the road is composed and with the character of the traffic passing over it. If the surface of a road is perfectly smooth, and the load per running inch of tire is sufficiently within the limit of resistance of the surface, the amount of wear is probably

[a] On the Cause of the Cementing Value of Rock Powders and the Plasticity of Clays. Allerton S. Cushman, Jour. Am. Chem. Soc., May, 1903.

insignificant. The moment, however, an irregularity of any kind occurs on the surface the wheels begin to pound at such points and water accumulates in the resulting depressions, which causes rapid deterioration. When the pressure per running inch of tire is too great for the road surface bad results soon follow. With crushed stone or gravel, not only should the pressure be within the limit of resistance of the rock of which the road is composed, but within the cohesive limit of the binder surface, for if this is not the case the passing wheels cause the material immediately beneath them to shift, furrowing the road and pressing the material up on either side of the furrow. This rutting is greatly increased by the consequent interference with the proper draining to the sides of the road, and the water is forced to accumulate on the surface, to gully out the road on grades, or make its way to the foundation. Always on a good road the resistance offered to compression by the material composing it exceeds the pressure of wheels, for if such were not the case the surface would soon be cut to pieces. It is, however, a frequent occurrence for the impact and even the pressure of wheels to exceed the limit of resistance of the binder surface of macadam and gravel roads. The pressure of wheels is distinctly beneficial to a road if it is sufficiently within the cohesive limit of the binding material and is evenly distributed over the surface. Indeed, it is necessary if a road is to be kept in a high state of perfection that it should be subjected to a sufficient amount of traffic to keep the material thoroughly compacted, and at the same time wear off a sufficient amount of fine material to take the place of that carried away by wind and rain.

CHEMICAL AGENCIES.

It has frequently been remarked by writers on the subject, that the chemical decomposition of materials plays an important part in the deterioration of roads. If wood and asphalt are used this may be the case, but the writer is convinced that undue importance has been attached to this agency as regards most of the road materials. In a warm, dry climate there is practically no limit to the life of rock. This fact is exemplified by many of the structures of antiquity, such as the pyramids of Egypt, composed of limestone and granite, which have stood for many centuries, while the rock has undergone but little change. In such a climate this would be the case with almost any variety of rock, but in a humid climate with a great range of temperature less durability is to be expected. In all cases, however, the durability of rock is extremely great as compared with the life of a road. All rain and surface waters contain a sufficient amount of carbonic acid to dissolve carbonates of lime and iron, and when charged with the humus acids derived from the decomposition of animal and vegetable matter certain of the rock-making minerals containing magnesia, potash, soda, lime, iron, and even silica, are rendered soluble. There is also a small amount of sulphuric acid present in rain water in the vicinity of large cities. The rocks most affected by these reagents are the limestones and rocks having a matrix of lime and iron, but we find the resulting disintegration, in rocks likely to be used in road making, practically negligible when compared with that due to other agencies to which roads are subjected. Professor Pfaff, of Erlangen, subjected to atmospheric erosion specimens of limestone and granite. The annual loss undergone by the limestone was estimated to be equal to the removal of a uniform layer of the general surface about 0.01 mm in thickness, while the granite lost 0.0076 mm.[a]

Even with roads constructed of the most soluble rocks it can be seen that this action from a road-building standpoint is extremely slow. The crushed stone below the surface would be subjected to but little running water, while the amount of the binder that might be taken into solution would be insignificant when compared with the loss through other agencies of wear. The writer compared six thin sections of fresh diabase (trap) with six other sections from the same rock ledge which had been in a roadbed for nine years, and so far as could be observed with the microscope no change whatever had taken place in the plagioclase and augite of which the rock is composed, or in the rock as a whole. In specimens of trachyte examined in the same way, one of which had been in a roadbed for twelve years, no alteration was noticeable. This subject has been fully treated by the writer in a former publication.[b]

PHYSICAL AGENCIES.

It is very doubtful whether the effect of freezing is injurious to road materials that absorb water even in considerable amounts, but at all events it is probably very small when compared with the destruction wrought by this same agency on the roadbed as a whole. One hundred volumes of water expand on freezing to 109 volumes of ice. If expansion is prevented the pressure developed on cooling the water 1 degree below its normal freezing point is 144 tons per square foot. When we examine the subject closely it becomes apparent that the action of frost on road materials is not so great as it at first seems. In the following table is given the percentage of water absorbed by the more important road materials.

[a] Pfaff, Sitz. k. k. Bayer. Akad., 1888.

[b] Report of the Massachusetts Highway Commission, 1900.

TABLE I.—*Water absorbed by the principal rock species.*

Name of material.	Number of samples.	Maximum.	Minimum.	Name of material.	Number of samples.	Maximum.	Minimum.
		Per cent.	*Per cent.*			*Per cent.*	*Per cent.*
Amphibolite	6	0.32	0.10	Granite	15	0.89	0.06
Andesite	3	1.30	1.16	Limestone	46	2.84	.03
Basalt	6	4.34	.06	Peridotite	1	.14	.14
Chert	11	2.72	.25	Quartzite	4	.82	.06
Conglomerate	2	2.43	1.60	Rhyolite	9	2.40	.02
Diabase	12	.48	.05	Sandstone	7	8.84	.30
Diorite	7	.59	.11	Schist	16	.59	.11
Dolomite	16	2.95	.04	Shale	3	3.07	.81
Eclogite	2	.04	.03	Slag	2	2.57	.34
Felsite	2	.20	.01	Slate	2	.30	.24
Flint	1	.13	.13	Steatite	1	.11	.11
Gabbro	1	.05	.05	Syenite	1	.18	.18
Gneiss	6	.18	.05				

The table shows that the amount of water absorbed by the best rocks for road making is small, but even where the amount is very large the action of frost does not seem to be markedly injurious. The following statement has been made concerning the effects of frost on paving brick:

The last two years the city of Peoria has conducted freezing tests, which are not completed, but they have gone far enough to show that the average brick could absorb 6 or 8 per cent and still not be affected by repeated freezing. If the absorption is that high, the brick would be soft and the wearing away under traffic would be such that the brick should be rejected for paving. [a]

While subjecting saturated paving bricks or fragments of rock to a freezing temperature may injure them but little, yet when an entire road surface freezes the effect is very different, for the absorptive power of the road is, with most materials, far greater than that of the material itself, and the strength of the road as a whole is far less than that of its individual components. In the case of pavements which have but little yield, such as brick and stone block on concrete foundations, the stresses set up by freezing must be very great.

By far the most destructive work of frost is effected on crushed stone or gravel roads. If the construction is defective and the maintenance poor, water accumulates in the body of the road, which spreads the material so much on freezing that the bond in some cases is destroyed, and in other cases much weakened. Experiments have been made to determine the increase in volume of wet rock dust, similar to that composing the binder of macadam roads, when subjected to the action of frost. Compressed briquettes of the dust were saturated with water and exposed to a temperature considerably below the freezing point for twelve hours. They were carefully measured

[a] Proceedings of the Illinois Society of Engineers and Surveyors, 1897.

with a micrometer screw before and after freezing and were found, on the average, to have increased in volume by about one-half of 1 per cent, the maximum increase being less than 1 per cent.

The agencies of destruction to roads, which have already been considered, are alike in one respect—they cause only abrasion and disintegration to the materials composing the road, while wind and rain carry away all the material loosened by these factors. Wind and rain are, therefore, the chief agents that remove material from a road, and as their action is incessant the loss is very great. From elaborate measurements made by the National School of Roads and Bridges of France, it appears that about 7 cubic yards of material per mile per annum are transported from the macadam roads of France. Undoubtedly this loss must vary widely in different localities and with different materials, and therefore such general results are not applicable to individual cases. The accumulation of water on the surface and its constant penetration to the foundation, together with the continual washing that takes place, make the action of water the most serious element of destruction that the road builder has to combat.

SERVICE TESTS.

The term "service test," as here used, does not refer to the informal tests that every material receives in service, the results of which form the main part of our experience with it, but to those formal, competitive tests that are frequently inaugurated in order to determine the relative merit of various articles or the efficiency of various processes. In the case of paving bricks, for instance, a number of different brands are laid in the same street and subjected to the action of traffic for an extended period, observations of the rate of wear being made from time to time.

These service tests in the case of road materials are of limited value. In the first place, it is difficult to determine the exact significance of the observed results because of the variability of the conditions and the indefiniteness of our knowledge of them. Further, the results of the test can not always be expressed definitely or in units that will be agreed upon, and thus much confusion will arise in the attempt to report the results. Again, a given material which proved best under one set of conditions with respect to climate, traffic, and topography, might be entirely unsuited to different conditions. Another practical objection is that a large expenditure of money and a prohibitory lapse of time, involving in some cases a change of traffic conditions, are necessary before any conclusions can be drawn relative to a matter which usually must be settled without great expense or delay.

The value of materials used for other purposes than road construction is in most cases satisfactorily determined by laboratory tests in which the exact conditions of service may or may not be approximated, according as it is difficult or impracticable to duplicate them. The essential requirement of such laboratory tests is that they shall be uniform, well defined, and directed to the measurement of the useful properties of the material. The samples must be submitted to the conditions which are exactly known and the elements or combination of elements of endurance and value isolated and determined quantitatively.

The nature of the agencies of service being known, and the degree to which the material possesses mechanical properties useful in resisting these agencies having been determined by test, the value of the material for any given service may be predicted. In case materials do not differ widely in some element of value it is necessary to resort to known and constant conditions of laboratory tests in order to determine their relative merit. The reliability of laboratory tests may be determined by applying them to appropriate materials the quality of which is known from experience in service. It is well to remember that what are apparently small differences of quality in a material will result in large differences of expense of maintenance and of road life. It is not too much to say that the life of a macadam road costing from $4,000 to $10,000 per mile may be from two to twenty years, depending upon a proper choice of material to suit the local conditions. The need and usefulness of proper laboratory tests to determine the essential qualities of road materials is thus evident.

Certain formal competitive tests of materials are, however, to be noted. Various brands of paving brick have been laid in the same street with a view to determining their relative merit and to check the results of the rattler test. Such tests are in progress in the cities of Washington, Baltimore, and Detroit.

In France elaborate data have been collected. In 1865 tests were begun on the national roads of France to determine the quality of the various materials of construction and ultimately to ascertain for each department the materials best adapted for its roads. Careful measurements were taken of the depth of stone for all the national roads by digging trenches, alternately from one side of the road to the center, so as to give a complete section of one-half of the road. This test was repeated in 1874, 1886, and 1893, the last measurements requiring over a half million trenches. These measurements were taken for the purpose of determining accurately the amount of stone worn off annually. At the same time a census was taken of the traffic passing over each road. Each division engineer was also required to build short sections of road of each available rock in his district along the same line of travel. All the materials of construction and maintenance were carefully measured and the results of wear observed.

Observations were taken over 22,000 miles of road. The traffic was classified and rated as follows:

(1) Each horse hauling a public vehicle or a cart loaded with produce or merchandise, 1.

(2) Each horse hauling an empty cart or a private carriage, $\frac{1}{2}$.

(3) Each horse, cow, or ox unharnessed, and each saddle horse, $\frac{1}{5}$.

(4) Each small animal (sheep or goat), $\frac{1}{20}$.

A record of traffic was made every thirteenth day throughout the year, and an average taken to determine the amount. The general average over all the roads in 1893 was 170.6 units of travel. To repair the roads there had been required an average of 49 cubic yards per mile and per 100 units of travel. The detailed accounts of this work are published in the official report of the minister of public works of France,[a] and offer a mass of data which, when combined with the results of laboratory tests, should be of great service in determining the value of the latter. The results of these elaborate service tests show, in general, a decided agreement with the results of the laboratory tests which were conducted at the same time. Since the investigation described laboratory tests have been the basis of selection of road materials in France.

In Portugal some attempt has been made to determine on a large scale the wear of roads and its relation to laboratory tests. A census of the traffic was kept at the tollgates and the wear was determined by making observations of the thickness of the roadbed whenever excavations had to be made. The results of these observations have not yet been published, but in a ministerial report it is stated that the laboratory tests indicated very clearly the best materials for use.

HISTORICAL REVIEW OF ROAD-MATERIAL TESTS.

It is only comparatively of recent years that tests of materials of construction have been carried on in a systematic way and the history of road-material testing is of still more recent date. Doubtless the ancient Roman engineer satisfied himself of the suitability of his materials to the end in view, but this was probably done in a very general way, or some records would have come down to us of the methods employed. Many of the earlier writers on macadam road building noted the superiority of wear in certain varieties of rock, and reference is often made to the desirability of hard and tough rock. As early as the middle of the last century compression tests were made on rocks in the endeavor to determine their road-building quality. The systematic testing of road materials may be said, however, to have been begun during the decade opening with 1870, in France, where it has been

[a] Campau, A. P. Rockwell, Roads and Pavements in France.

steadily developed ever since. The Portuguese Government, the next to take up the subject, adopted some of the French tests and conducted them with much precision. While the importance of the subject has been recognized in England, yet aside from the limited investigations of a few individuals, almost nothing has been done. The same is true, even to a greater extent, of Germany, and the other continental nations have left the subject practically untouched. The United States is the only other country where this work has been carried on in a systematic way.

In 1893 the Massachusetts highway commission, in collaboration with the Lawrence Scientific School of Harvard University, established a road-material laboratory at the latter institution. Although paving-brick tests had been made previously, this was the first laboratory in the United States for testing road materials in a systematic way. The Deval abrasion test was adopted, and tests for determining the cementing power of rock dust were first developed there. Since then laboratories have been equipped with appliances for testing road materials by the Maryland Geological Survey, Columbia University, Wisconsin Geological Survey, Cornell University, the University of California, and the United States Department of Agriculture.

TESTS OF ROAD MATERIALS IN FRANCE.

In December, 1878, the French commission on national roads decided to introduce certain mechanical tests at the laboratory of the School of Roads and Bridges, to be conducted in addition to and parallel with service road tests. The Deval test, bearing the name of its designer, for determining the resistance offered by macadam rocks to abrasion had already been pronounced by the street department of the city of Paris to be useful and reliable in testing the rock used in contract work and for selecting new quarries. This test was accordingly adopted by the commission and a laboratory was founded, which has steadily increased in usefulness.

The Deval Machine.

This machine, as far as the writer has been able to ascertain, was the first one designed especially for testing road materials. It was first exhibited at the Paris Exposition of 1878, and then consisted of two iron cylinders fastened to a shaft, so that the axis of each cylinder was at an angle of 30 degrees with the axis of rotation. The shaft which held the cylinders was supported on bearings, and had at one end a pulley wheel by which the cylinders were revolved and at the other a revolution counter. Each cylinder, 20 cm in diameter and 34 cm

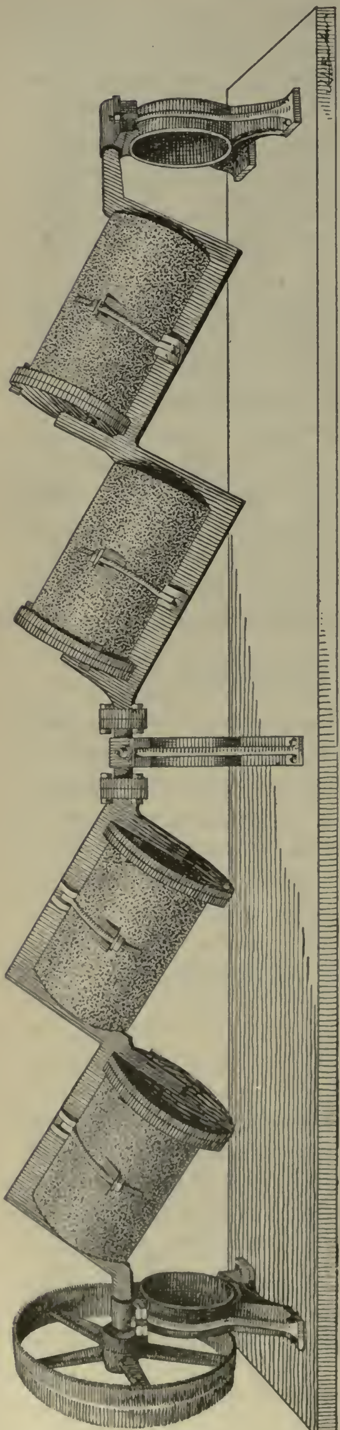

FIG. 1.—Abrasion machine.

in depth, was closed at one end and had a tightly fitting iron cover for the other. A cut of a similar machine slightly modified and in use in the Road Material Laboratory is shown in fig. 1.

In adopting the Deval machine, the only change made by the School of Roads and Bridges was to increase the number of cylinders to eight in order to increase the output. The eight cylinders are mounted four by four on two parallel shafts geared to rotate with the same rapidity. This arrangement renders it possible to make eight tests simultaneously. The method of operation is as follows:

The rock to be tested is broken in sizes as nearly uniform as possible, each fragment being made to pass in all positions through a 6-cm ring. Five kilograms of rock thus prepared and previously cleansed by washing and subsequent drying are placed in one of the cylinders. The cover is then bolted on and the cylinders revolved at the rate of 2,000 revolutions per hour. The fragments of stone are thrown from one end of the cylinder to the other twice in each revolution, and thus grind and pound against one another and the ends of the cylinder. At the end of five hours, or 10,000 revolutions, the machine is stopped, the cylinders opened, and the contents emptied into a basin. The cylinder and the cover are carefully washed and the water used is poured into the same receptacle. Each stone is then washed and brushed under the water until all adhering dust is removed. After drying, the detritus is separated into the following three sizes: Above 1 cm, between 1 cm and 0.16 cm, and below 0.16 cm. Only the material below 0.16 cm, the weight of which is recorded, is used for the purpose of the test.[a]

At first a standard rock of superior wearing quality was always placed in one of the cylinders as a standard of comparison, and the proportion of the weights of the dust under 0.16 cm from the standard rock and from the rock to be tested was assumed to give their relative resistance to abrasion. It was found, however, that only the best varieties of rock gave less than 100 grams of powder under 0.16 cm, i. e., 20 grams per kilogram of rock, or 2 per cent of their weight. The number 20 was therefore adopted as a standard of excellence, and the "coefficient of wear" for any rock tested may be obtained by the following formula:

$$\text{Coefficient of wear} = 20 \times \frac{20}{W} = \frac{400}{W}$$

in which "W" is the weight in grams of the detritus under 0.16 cm in size obtained per kilogram of rock used.[a]

Compression Test.

In addition to the test made with the Deval machine the following compression test was later adopted: This test is made on 25 mm cubes of rock with a hydraulic compression machine. The cubes are sawed at the laboratory from specimens carefully selected to represent the average quality of the rock. At least three cubes of each sample are tested after desiccation either in the open air or at a temperature of 40° C., or after being saturated with water. The resistance offered by each cube is obtained in kilograms per square centimeter of bearing surface, and the average of the results furnished by the different cubes is used.

Experience having shown that the hardest rocks rarely resist a load greater than 2,000 kg per square-centimeter section, the commission adopted the coefficient 20 for the materials having this degree of resistance. This corresponds approximately to the resistance to compression of wrought iron. The coefficient of any rock, therefore, may be obtained by the following formula:

$$\text{Coefficient} = \frac{3,000}{20} + E = 150\ E.$$

"E" represents the breaking load in kilograms per square-centimeter section. To determine the density of rock the cubes used for the compression test are measured and weighed. This is undoubtedly the most accurate of any of the simple methods for making this determination.

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[a] Results obtained from this test in the Road Material Laboratory are given in Table II, page 26, and in Table A of the Appendix.

THE DORRY TEST.

The test for hardness is made with the Dorry machine. The specimens to be tested are sawed into rectangular prisms 8 cm high with a base 4 cm by 6 cm. These specimens are placed, two at a time, so that they rest on the upper surface of a circular grinding disk of cast iron, which is rotated in a horizontal plane by a crank. They are held in clamps so arranged that the bases of the specimens rest on alternate sides of the grinding disk 26 cm from the center. The specimens are weighted so that they press against the grinding disk with a pressure of 250 grams per square centimeter. Sand of a standard

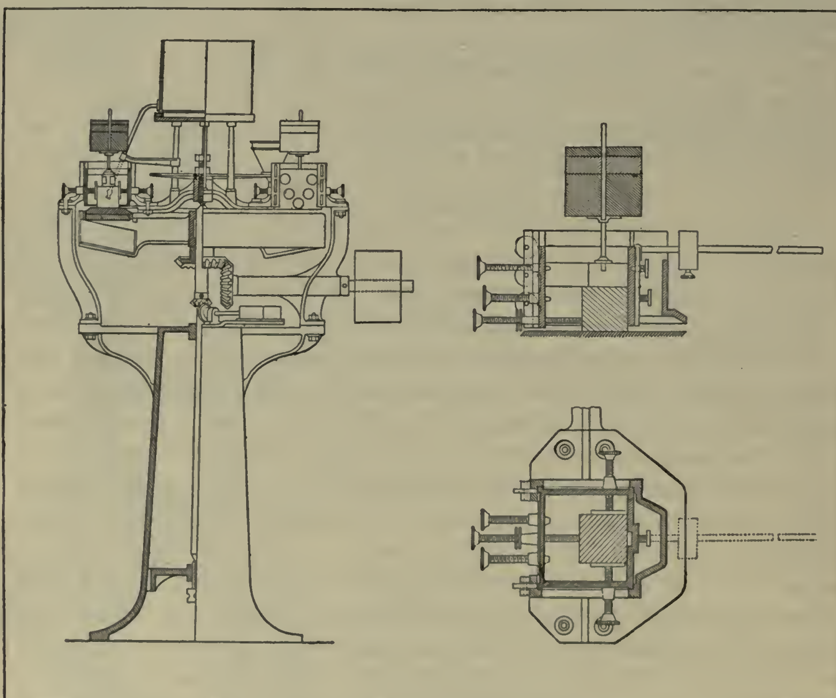

FIG. 2.—Dorry machine for determining hardness.

quality and size, obtained by crushing quartzite rock and screening it, is fed onto the disk from a funnel. The quantity of sand used in each test is 4 liters. The disk is rotated at the rate of 2,000 revolutions per hour for two hours. A drawing of this machine, slightly modified, is reproduced in fig. 2.

After 2,000 revolutions the specimens are reversed to ascertain if there is any difference in wear between the two ends and to make the result approach more nearly a general average of the samples. The diminution in the height of the specimen is measured and its loss in weight determined after each 1,000 turns of the grinding disk. No coefficient of wear has been established for this test, but the loss in height undergone by each specimen after 4,000 revolutions of the disk is taken as the result of the test and serves for comparison. Tests are always made on at least three specimens of each sample, and the final result is taken from their average.

Impact Test.

The impact test is made with a machine especially designed for the purpose at the national laboratory. It resembles a pile driver very closely in principle, consisting of a hammer with vertical guides to direct its fall. The hammer is raised by a cord which passes over a pulley at the top of the guides, and can be released at any desired height, from which it falls upon the test piece which is held below by clamps. Two hammers are employed, one weighing 42 kg and the other 20 kg with falls of respectively 100 cm and 80 cm. The number of blows necessary to crack the specimen, and also the number necessary to produce its complete destruction, is noted. The test is made upon 4 cm cubes, at least three cubes being used for each specimen with each hammer. Occasionally some other tests are used, including the determination of porosity, the effect of frost, and transverse breaking.

Tests on Wood Paving Blocks.

The tests most commonly used for wood paving blocks consist of the determination of their resistance to wear when saturated with water; resistance to compression, resistance to impact, the determination of expansion by absorption of water, and the measurement of the thrust exerted when expansion is partially prevented. The test for wear is made with the Dorry machine. The specimens consist of prisms of the same dimensions as those used for testing the hardness of paving stones. The specimens are placed in the machine with the grain of the wood at right angles to the grinding disk. The only difference in the conduct of the test is that emery is used as the grinding agent instead of quartz sand. Only the loss in height of the specimen is recorded.

The compression test is made with a hydraulic press upon prismatic specimens, with a base 8 cm square and a height equal to that of a paving block, the grain of the wood being parallel to the direction of the load. The test specimens are either dried at a temperature between 30° and 40° C., or they are saturated with an amount of water estimated to be equal to that absorbed by a paving block in service.

The resistance to impact is tested with the machine described above upon prisms having a base of 6 cm square and a height equal to that of a paving block. The test piece is placed in a cast-iron case 7 cm square, open both at the top and the bottom, and is held in place by a resinous cement which completely surrounds it, the top of the prism projecting about 1 cm above the case. The 20 kg hammer is employed in this test, with a height of fall of 200 cm. The number of blows of the hammer which cause an appreciable breakage is noted. Failure in the test piece is indicated by a smaller rebound of the hammer and a diminution in the height of the specimen. Three dried and three wet specimens are subjected to this test.

For determining the thrust caused by absorption when expansion is partially prevented, whole paving blocks are used. The block, after thorough desiccation, is placed in a water-tight receptacle and held between two plates at top and bottom, so that the top face of the test piece rests against a block of cast iron, which is stationary. The lower plate is supported on the small lever arm of a cement-testing machine. Water at a temperature of 30° C. is poured around the paving block, and as expansion takes place the lever arm of the machine tends to rise. When it rises a valve is opened through which mercury pours into a vessel supported at the end of the arm till the arm comes back to mid-position, when the valve is closed. As the lower plate is fixed when the long lever is in its mid-position, and as this arm is always kept automatically in that place the specimen is prevented from extending longitudinally. The weight of the mercury in the vessel at the end of the short arm is at any moment a measure of the force exerted by the test piece, and as the vessel is supported by a spring balance, this can be read at any, time. Observations are made at first at intervals of three hours then at intervals of twelve hours, and finally at intervals of twenty-four hours till all increase ceases. It will be seen that while this test does not reproduce closely the conditions that exist in practice, the results are of value in giving some indication of the amount of thrust to be expected. After the test the specimens are weighed to ascertain how much water has been absorbed.

No mechanical tests have yet been devised, or considered necessary, for asphalts. Chemical analyses are made, however, to determine the proportion of bitumen, sand, calcium carbonate, clay, pyrites, etc.

TESTS OF ROAD MATERIALS IN PORTUGAL. [a]

The laboratory testing of road materials was first taken up in Portugal in 1881, in the district of Santarem. The Deval test of the French School of Roads and Bridges was adopted, and over sixty varieties of rock were tested. The basalts, diorites, and certain of the granites from the valley of the Tagus gave coefficients of wear as high as 24. This is a higher coefficient than that of flint, which previous to this test was thought to be the best macadam rock, but subsequent trials on the road have proved this to be a mistake. The coefficients of the limestones tested ranged from 2 to 17. Those from

[a] Jornal dos Engenheiros Civiles Portuguezes, 1882, **13**: 150. Revista das Obras Publicas e Minas, vols. 13 and 24; also special ministerial report.

10 to 17 gave good results on roads where travel was light, while those below 10 were found to be too soft.

Compression tests are also carried on at the laboratory for testing materials at Lisbon, which is equipped with three compression machines. Tests can be made on 10 cm, 7cm, and 5 cm cubes, as desired but the smaller cubes, which are crushed both dry and wet, are generally used for testing road materials. No coefficient has been worked out for this test. The number of kilograms per square centimeter required to destroy a test piece is used for comparison. All samples are sent to the laboratory by the directing engineer of the district from which they come. The results of these laboratory tests have been found to be in agreement with the limited observations made on the actual wear of roads.

HISTORY OF PAVING BRICK TESTS.

An account of the work of the National Brick Manufacturers' Association in establishing a standard rattler test, and of the critical and confirmatory studies of other investigators arising therefrom, would give a fairly complete history of the development of paving brick tests.

Formerly reliance was placed entirely on the decisions of the street inspector, who rejected individual bricks that were defective in form or hardness. The necessity for such work has not disappeared, even with the development of the present perfected tests. Many engineers have used for some time the cross breaking and crushing tests, or else the absorption test as an index of internal structure, but gradually specific tests and standards of quality have been reached through experience.

The rattler test has been used for some years. In 1895 the National Brick Manufacturers' Association appointed a commission on paving brick tests. The first report[a] of work, issued in 1897, included the results of the following studies: The rattler test by Edward Orton; the absorption test by H. G. Wheeler; the cross-breaking test and additional studies of the rattler test by F. F. Harrington, and specifications for the cross-breaking test by J. B. Johnson. As a consequence of these reports the rattler test was chosen as the most significant and reliable, and the size and speed of the rattler and the duration of the test were specified in accordance with the present standard, although no abrasive shot were then used in the rattler. The absorption test was condemned because it did not indicate the the relative value of different brands of paving brick. It was admitted, however, that there existed in the case of any given brick a particular per cent of absorption which indicated whether the brick had been properly burned. The fact was also brought out that an

[a] Report of the Commission appointed to Investigate the Subject of Paving Brick Tests. T. A. Randall & Co., Indianapolis.

observation extending over a period of less than one week was not of sufficient duration to represent the entire absorptiveness of the brick. The directions given for conducting the test were to weigh five abraded bricks after drying for forty-eight hours at a temperature of 250° F., then immerse them for forty-eight hours and reweigh.

The cross breaking and compression tests were left optional. For the former test knife-edges rounded both transversely and longitudinally were recommended and ten bricks were to be tested. For the latter test five half bricks were to be used and loaded on edge through plaster of Paris beds.

About the same time a study of the rattler test was conducted at the University of Illinois by A. N. Talbot to determine the proper composition of an abrasive agent for use in the rattler test. It appeared[a] that it was necessary to use a mixture of large and small cast-iron shot in order to distinguish between soft and hard brick in the rattler test.

Minor studies of the rattler test were made at Purdue University by W. K. Hatt[b] and at the State Agriculture College of Iowa by A. Marston.[c] The former showed that the moisture condition of the brick was important. The latter made a study of the cross-breaking test and showed that the large variation in individual results was due to real differences in the quality of the bricks tested.

Gomer Jones[d] described a rattler in which the bricks were held in pockets cast on the staves so that the interior of the rattler was lined with brick, on the surface of which lining the shot filling rolled and produced impact and abrasion. The committee on technical investigations of the National Brick Manufacturers' Association subjected Talbot's "shot process" and the Gomer-Jones process to a thorough examination by comparing the action of the two processes on bricks of known grade. The results reported in 1900[e] favored the use of that form of shot suggested by Talbot, and a new standard of the National Brick Manufacturers' Association, which prescribed a shot filling, was accordingly adopted. The Jones rattler was found to be mechanically defective. This rattler was improved by Talbot and a new investigation of the action of the improved rattler compared with the action of the standard process was instituted. The results given in a preliminary report of the committee of the National Brick Manufacturers' Association in August, 1901, showed that reliance could be placed on both the standard process and the Gomer-Jones process as modified by Talbot. A description of the standard method as finally adopted by the National Brick Manufacturers' Association will be given among the methods of the Road Material Laboratory.

[a] The Technograph, University of Illinois, No. 12, 1898.

[b] Proceedings Indiana Engineering Society, 1899.

[c] Proceedings Iowa Engineering Society, 1899.

[d] Columbus Meeting of N. B. M. A., 1899.

[e] Detroit Convention, February, 1900.

METHODS AND TESTS OF THE ROAD MATERIAL LABORATORY.

The Road Material Laboratory was established in December, 1900, in the Bureau of Chemistry. Up to the present time reports have been made on about five hundred samples, representing a geographical distribution over thirty-eight States of the Union and including a number of samples from Porto Rico and Cuba.

The primary object of this laboratory is to make standard tests on road materials, free of charge, for citizens of the United States. In addition to this allied problems may be presented for study, such as the suitability of clays for the manufacture of paving bricks, drain tiles, cements, etc., the testing of cements and concretes for road foundations, drains, gutters, and highway bridges. It is the intention of the Department to aid as far as possible in the solution of all the problems of road building, but more particularly those relating to rural highways. It is not, however, the policy of the Department to undertake scientific investigation or tests of materials for manufacturers or others who desire to use the information thus acquired to promote commercial ends.

Any person desiring to have road materials tested will, on application, be supplied with instructions for collecting and shipping samples to this laboratory. The tests as carried on at present are described in the following pages.

TESTS FOR ROCK AND GRAVEL.

Abrasion Test.

This test is almost identical with the Deval test already described under the French methods, the only difference being the omission of certain features not deemed strictly necessary, and a few modifications in the machine to simplify its operation and lessen the cost of construction. This machine, shown in fig. 1, p. 18, is made entirely of cast iron and has given excellent service. The test is made in the following manner: The sample to be tested is first broken in pieces that will pass in all positions through a 6 cm (2.4-inch) ring, but not through a 3 cm (1.2-inch) ring. The stones are then cleansed, dried in a hot-air bath at 100° C., and cooled in a desiccator. Five kilograms are weighed and placed in one of the cylinders, the cover bolted on, and the machine rotated at the rate of 2,000 revolutions per hour for five hours. When the 10,000 revolutions of the machine are completed the contents of the cylinder are placed on a sieve of 0.16 cm ($\frac{1}{16}$ inch) mesh, and the material which passes through is again sifted through a sieve of 0.025 cm (0.01 inch) mesh. Both sieves and the fragments of rock remaining on them are held under running water till all adhering dust is washed off. After the fragments have been dried in a hot-air bath at 100° C. and cooled in a desiccator they are weighed and their weight subtracted from the original 5 kg (11 pounds). The difference obtained is the weight of detritus under 0.16 cm ($\frac{1}{16}$ inch) worn off in the test, from which the French coefficient of wear is determined by the formula already given. Besides the French coefficient, the percentage of material under 0.16 cm in size is also reported. For a time another coefficient, called the Department coefficient, was used, which was obtained by subtracting 4,000 grams from the weight of the remaining fragments over 3 cm (1.2 inches) in size and dividing the difference by 10. This allows a possible range in results from 0 to 100, i. e., if 1,000 grams or 20 per cent of the material is abraded from the original 5 kg, the result will be 0, and the material is considered unfit for road making; if no dust is worn from the original 5 kg the result will be 100.

Although both the French and the Department coefficients are arbitrary, they have a distinct value. The French coefficient has been in use for many years, and is familiar to road builders throughout the East. At present both the French coefficient and the per cent of wear are reported, and the Department coefficient will also be given on application. In Table II are given the maximum and minimum percentages of wear and the French coefficient for all varieties of rock that have been tested in this laboratory, and in Table A of the Appendix the results on each sample tested are given.

TABLE II.—*Abrasion test.*

Name of material.	Number of samples.	Per cent of wear.		Coefficient of wear.	
		Maximum.	Minimum.	Maximum.	Minimum.
Amphibolite	6	4.6	1.5	26.7	8.5
Andesite	3	6.4	2.6	15.2	6.3
Basalt	6	16.6	1.7	23.6	2.4
Chert	10	27.9	2.7	14.6	1.4
Clay	1	19.1	19.1	2.1	2.1
Conglomerate	2	12.7	5.7	7.0	3.2
Diabase	14	6.3	1.2	34.5	6.4
Diorite	8	3.4	1.9	20.6	11.7
Dolomite	15	18.6	2.5	16.1	2.2
Eclogite	1	2.9	2.9	13.8	13.8
Felsite	2	3.4	1.9	21.3	11.9
Field stone (erratics)	1	5.0	5.0	8.0	8.0
Flint	1	7.2	7.2	5.5	5.5
Gabbro	1	2.9	2.9	14.3	14.3
Gneiss	6	5.2	1.9	20.7	7.7
Granite	15	14.8	1.8	21.7	2.7
Limestone	46	34.2	2.8	14.2	1.2
Mixed stone	1	8.7	8.7	4.6	4.6
Peridotite	1	3.6	3.6	11.1	11.1
Quartzite	3	3.6	2.2	18.2	11.1
Rhyolite	9	9.7	1.8	22.9	4.1
Sandstone	7	31.8	3.4	11.6	1.3
Schist	16	7.1	1.9	20.6	5.7
Shale	2	16.2	4.7	8.6	2.5
Slag	2	8.3	7.6	5.2	4.8
Slate	2	6.9	4.7	8.5	5.8
Syenite	1	2.8	2.8	14.4	14.4

Cementation Test.[a]

The binding or cementing power of rock dust is such an important element in road building that much time has been spent in the endeavor to devise a suitable test for determining the degree to which the various rocks and gravels possess this property. Many tests have been tried, but as yet only an impact test, carried on in a uniform manner as described below, has given satisfactory results.

One kilogram of the rock to be tested is broken sufficiently small to pass a 6 mm but not a 1 mm mesh screen. It is then placed in a ball mill and is ground for two hours and a half. This ball mill,

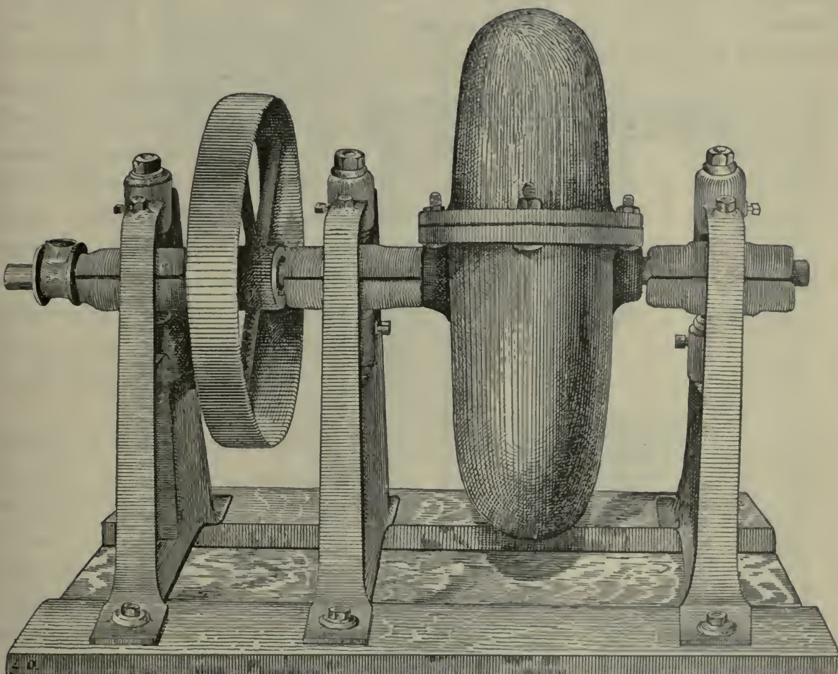

FIG. 3.—Ball mill.

shown in fig. 3, contains two chilled iron balls which weigh 25 pounds each, and is revolved at the rate of 2,000 revolutions per hour. It was found by experiment that grinding rock thus prepared for two hours and a half was sufficient to reduce it to a powder that would pass through a 0.25 mm mesh. The dust thus obtained is mixed with water to about the consistency of a stiff dough, and is kept in a closed

[a] This test, and the necessary machines for conducting it, were designed and developed by the writer for the Massachusetts Highway Commission and the Road Material Laboratory. The impact machine at present used was built especially for this laboratory by the Maryland Geological Survey, under the direction of Mr. A. N. Johnson, highway engineer to the survey, who made several useful modifications in the machines.

jar for twenty-four hours. About 25 grams of this dough is placed in a cylindrical metal die, 25 mm in diameter, which can be seen in fig. 4. A closely fitting plug, supported by guide rods, is inserted over the material, which is then subjected to a pressure of 100 kg per square centimeter.

It is most important that these briquettes should be compressed in a uniform manner, and for this a special machine has been designed (fig. 5). The die is placed on an iron platform supported by a piston rod, which is connected directly with a hydraulic piston below. Water from a tank is admitted to the hydraulic cylinder through a small orifice in the pipe. As the piston rises the platform and die are carried up with it, the plug of the latter coming in contact with a yoke attached to a properly weighted lever arm. When the lever arm is raised one-eighth of an inch it closes an electric circuit which trips a right-angle cock, shutting off the water and opening the exhaust. One minute is required to compress a briquette, and the maximum load is applied only for an instant. By this device practically uniform conditions are obtained.

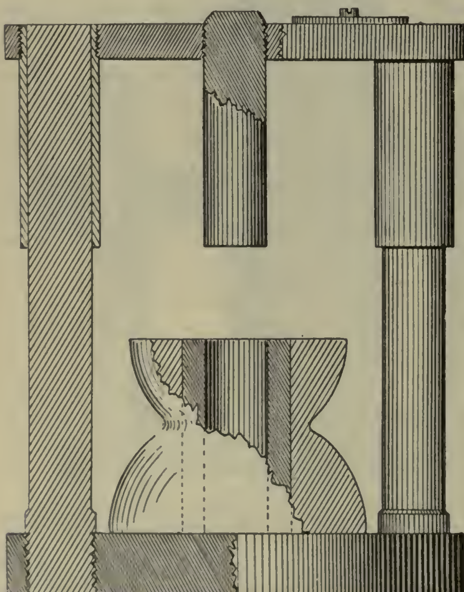

FIG. 4.—Briquette die.

The height of the briquette is measured, and if it is not exactly 25 mm the requisite amount of material is added or subtracted to make the next briquette the required height. Five briquettes are made from each test sample, and allowed to dry twelve hours in air and twelve hours in a steam bath. After cooling in a desiccator they are tested by impact in a machine especially designed for the purpose (fig. 6). It consists of a 1 kg (2.2 pounds) hammer (*H*), which is guided by two vertical rods (*D*). The hammer (*H*), which ends in a small cone at the top (*L*), is caught on the lower side of the cone by two spring bolts (*S*) and is lifted by a crosshead (*I*) which is joined to a crank shaft above. A vertical rod (*P*), which is directly over the hammer cone, can be adjusted by thumbscrews to give a drop to the hammer varying from a fraction of a millimeter to 10 cm. This rod has a hollow cone at its lower end into which the cone of the hammer head is thrust when the hammer is lifted by the crosshead (*I*). When the cone of the hammer head is brought into the cone of the adjusting rod the hammer is

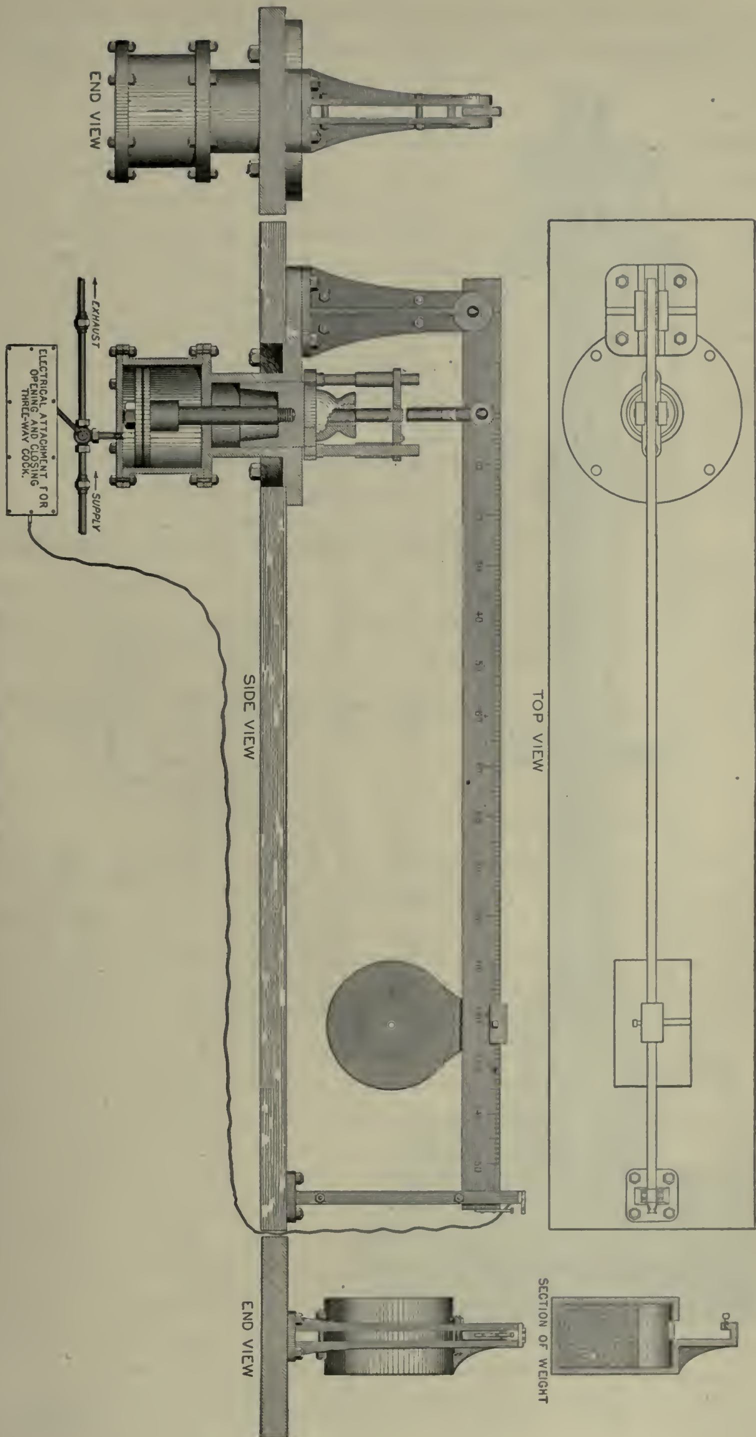

FIG. 5.—Briquette machine.

exactly centered and brought free of the guide rods (*D*). As the cross-head (*I*) continues to rise, the bolts supporting the hammer, which are

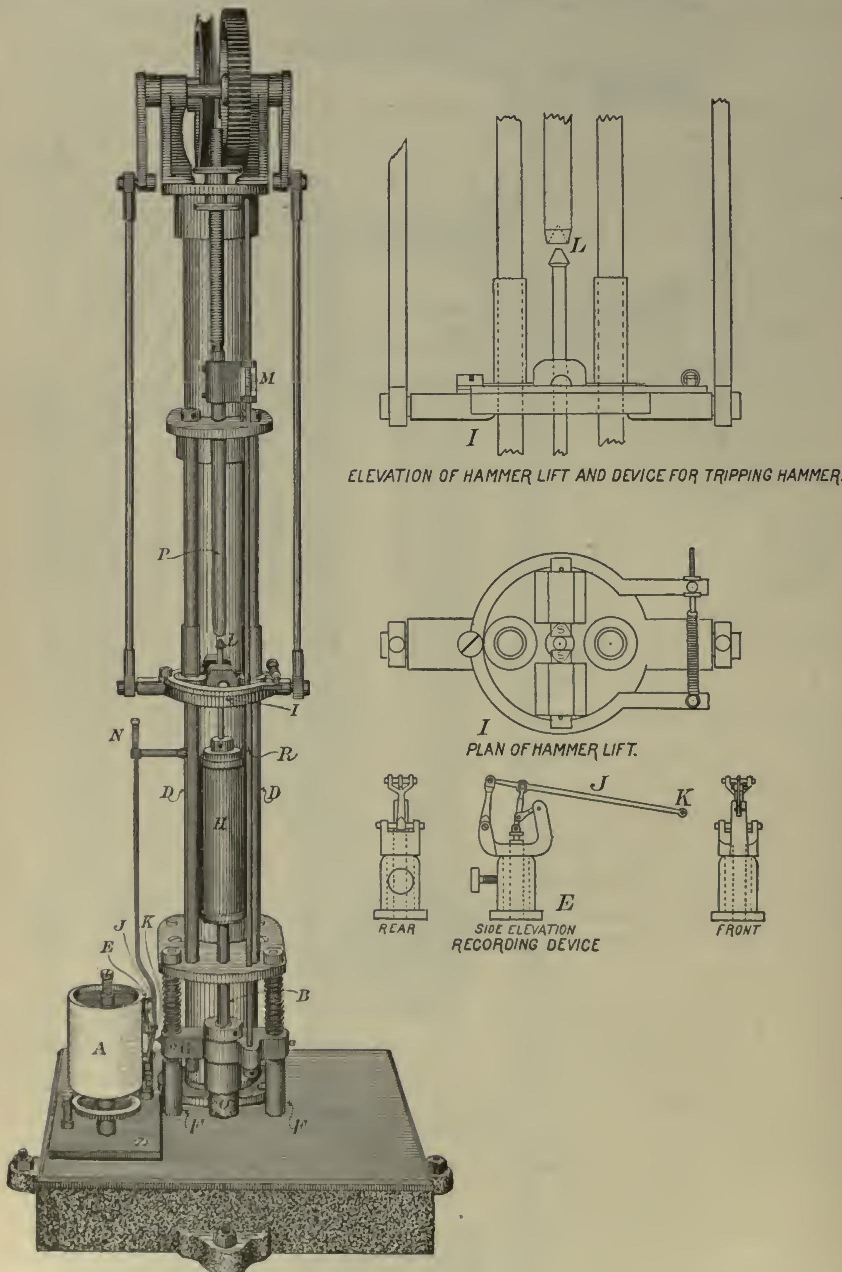

FIG. 6.—Impact machine to determine cementing value of rock.

tapered at an angle of about 45°, are thrust open by the sloping head of the adjusting cone rod (*P*) releasing the hammer, which falls on a flat-end plunger (*B*) of 1 kg weight, which is pressed upon the briquette (*O*) by two light spiral springs surrounding the guide rods (*F*). This plunger (*B*) is bolted to a crosshead (*G*). A small lever (*J*) holding a brass pencil (*K*) at its free end, is connected with the side of the crosshead, by a link motion arranged so that it gives a vertical movement to the pencil five times as great as the movement of the crosshead. The pencil is pressed against a drum (*A*), and its movement is recorded on a slip of silicated paper fastened thereon. The drum is moved automatically through a small angle at each stroke of the hammer; in this way a record is obtained of the movement of the crosshead during and after each blow of the hammer. To the crosshead (*G*) is fastened a steel rod (*R*) which passes up through the crosshead (*I*) and through a piece of metal securely attached to the cone rod (*P*). At this junction a vernier scale is graduated, by means of which the height of blow of the hammer can be accurately set to 0.1 mm, and by lowering the cone rod until it rests on the hammer cone (*L*) the height of the briquette can also be measured to 0.1 mm.

The standard fall of the hammer for a test is 1 cm (0.39 inch) and this blow is repeated until the bond of cementation of the material is destroyed. The blow producing failure is easily ascertained, for when the hammer falls on the plunger, if the material beneath it can with-

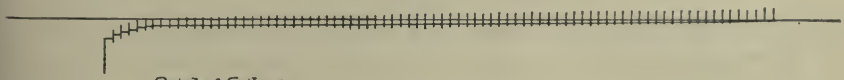

FIG. 7.—Diagram showing point of failure in cementation test.

stand the blow it recovers; if not, the plunger stays at the point to which it is driven, and in either case the behavior of the test piece is recorded on the drum. The automatic record thus obtained from each briquette is filed for future reference. A copy of one of these records is shown in fig. 7. The number of blows required to destroy the bond of cementation or resilience, as described above, is noted and the average obtained upon five briquettes is given as the cementing value.

The problem of holding the test piece rigidly under the intervening plunger, so that it would not be subjected to lateral movements and transverse strains, is one which has given much difficulty. Until recently a small brass plate with a beveled hole slightly larger than the diameter of the briquette was used, but it was found that the test piece was often seriously abraded by the side thrust developed. Later attempts to secure the briquette by various clamping devices were not satisfactory. Finally the method was adopted of placing a drop of thick shellac on the bottom of the test piece, which caused it to adhere firmly to the bedplate. Careful attention to such details as these is necessary in order to get satisfactory results from this test.

The original method for molding the briquettes was worked out in the laboratory of the Massachusetts Highway Commission and differs somewhat from the method as described above. In the earlier practice the requisite amount of rock dust to make a briquette was weighed out while dry, mixed with 3 to 4 cubic centimeters of water, and the briquette immediately molded from the wet dust. It is well known to practical road builders that the binding power of many rocks increases under the combined influence of water and traffic as time goes on. This question has received a great deal of attention and investigation in this laboratory. Experiments have shown that the cementing value is increased if the dough made from a rock dust is allowed to stand for some time before being molded, and it is still more increased if the dough is kneaded. This is plainly seen in the results obtained on a sample of dolomite. This dolomite is a celebrated road-building material in the locality in which it is found, and its most marked characteristic is the way that its binding power increases after it has been on the road for some time. A series of experiments was conducted, bearing on this point, in which the rock dust was made to a stiff dough and briquettes molded at stated intervals. A new lot of dust was made up and well kneaded by hand for one hour. The results were as follows:

	Cementing value.
Dough tested at once	16
4 hours old	50
24 hours old	81
72 hours old	79
96 hours old	77
120 hours old	79
144 hours old	83
8 days old	81
Kneaded 1 hour	190

An inspection of this table clearly shows the importance of conducting the operations of this test under uniform conditions. In mixing the dust with water to form the dough, the operator should be trained to knead each specimen as nearly as possible in the same manner for the same length of time. After twenty-four hours standing in a closed jar a cementing value is developed which remains fairly constant. When carried out in a uniform manner by a skilled operator this test has no higher percentage of variation on homogeneous samples than is found in testing the tensile strength of cement briquettes. Road materials vary widely in this important property, but the test is undoubtedly of the highest comparative value and practicability, for it distinguishes between excellent, good, fair, and poor binding materials. It should be remembered that from the very nature of the materials to be tested it is impossible to expect a degree of accuracy such as is obtained in the testing of perfectly homogeneous substances.

The maximum and minimum results obtained from the tests of the cementing value of the various materials received in this laboratory are given in the following table, and in Table A of the Appendix are found the results obtained on each sample.

TABLE III.—*Cementing values of road-building rocks.*

Name of rock.	Number of samples.	Maximum.	Minimum.	Name of rock.	Number of samples.	Maximum.	Minimum.
Amphibolite	6	36	3	Gravel	31	725	2
Andesite	3	337	14	Gneiss	14	21	1
Basalt	9	72	2	Gabbro	5	131	12
Chert	16	1,083	10	Granite	25	77	2
Clay	13	4,000+	35	Limestone	52	231	8
Conglomerate	3	327	12	Peridotite	1	3	3
Diabase	26	110	2	Quartzite	7	47	2
Diorite	9	137	1	Rhyolite	9	577	1
Dolomite	15	161	2	Sandstone	14	323	8
Eclogite	2	20	3	Schist	18	272	2
Felsite	7	101	2	Shale	3	985	62
Field stone (erratics)	48	46	5	Slag	2	137	19
				Slate	2	202	151
Flint	1	31	31	Syenite	2	11	2

TEST FOR TOUGHNESS.[a]

This test is made on 25 mm × 25 mm (0.98 inch) rock cylinders with an impact machine especially designed for the purpose (fig. 8). Instead of a flat-end plunger resting on the test piece as in the cementation test, a plunger with the lower and bearing surface of spherical shape, having a radius of 1 cm (0.4 inch) is used. It can be seen that the blow as delivered through a spherical-end plunger approximates as nearly as practicable the blows of traffic. Besides this, it has the further advantage of not requiring great exactness in getting the two bearing surfaces of the test piece parallel, as the entire load is applied at one point on the upper surface. The test piece is adjusted so that the center of its upper surface is tangent to the spherical end of the plunger, and the plunger is pressed firmly upon the test piece by two spiral springs which surround the plunger guide rods. The test piece is held to the base of the machine by a device which prevents its rebounding when a blow is struck by the hammer. The hammer weighs 2 kg and is raised by a sprocket chain and released automatically by a concentric electro-magnet. The test consists of a 1 cm fall of the hammer for the first blow, and an increased fall of 1 cm for each succeeding blow until failure of the test piece occurs. The

[a] This test was designed by the writer while in charge of the laboratory of the Massachusetts Highway Commission, but was never put in operation. It has been very much modified in the Washington laboratory.

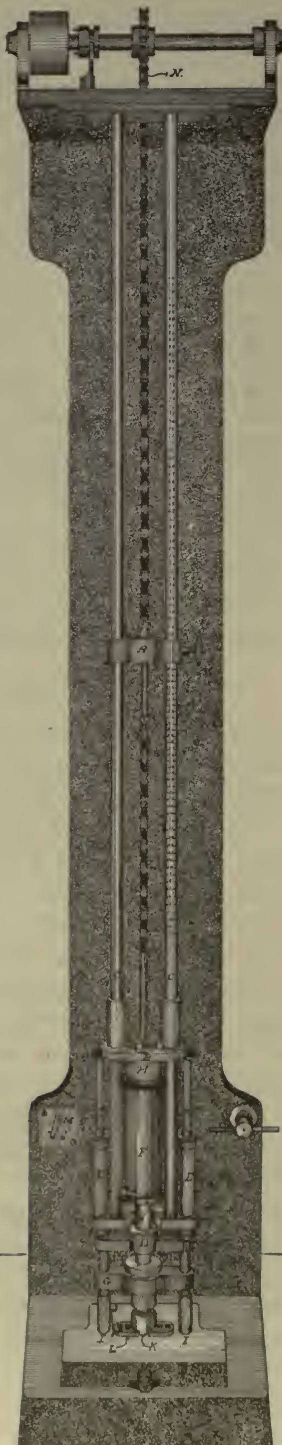

FIG. 8.—Impact machine for determining toughness.

number of blows required to destroy the test piece is used to represent the toughness. A sufficient number of results have not yet been obtained with this test to warrant their publication.

The cylindrical test pieces employed are made with a core saw designed for the purpose. It consists of a steel tube supported by journals in a vertical position and held in a cast-iron frame. A link motion lever rests on the upper end of the tube on a ball bearing. A spiral spring is attached to the free end of the lever by which the downward pressure of the tube can be adjusted. Water is fed in the top of the tube by a small rubber hose, and at the center is a pulley wheel by which the tube is revolved at about 800 revolutions per minute. The bottom or cutting end of the tube is set with bort by a specially designed method. This saw cuts very rapidly and the waste is very much less than in cube cutting, in addition to which the cylindrical test piece is better adapted for this test.

Absorption Test.

The method used for determining the absorptiveness of rock is not intended to give the porosity but merely the number of pounds of water that is absorbed by a cubic foot of rock in ninety-six hours. A smoothly worn stone, between 20 and 60 grams in weight, which has been through the abrasion test is used. After being weighed in air, it is immersed in water and immediately reweighed in water. After ninety-six hours of immersion it is again weighed in water. The absorptiveness of the rock is expressed by the following formula:

Number of pounds of water absorbed by a cubic foot of rock=

$$\frac{C-B}{A-B}\times 62.5$$

in which A is equal to the weight in air, B the weight in water immediately after immersion, C the weight in water after absorption for ninety-six hours, and 62.5 the weight of a cubic foot of water. From these weights the specific gravity and the weight per cubic foot of the rock are also determined.

The method first used by Gilmore,[a] and later by Winchell and Williams,[b] differs from this method in that the stone used in the test was taken out of the water in which it was immersed, its surface dried with a filter paper, and its weight taken every twenty-four hours until absorption ceased. The absorptiveness was expressed by giving the number of parts by weight of stone required to absorb one part by weight of water. The method used in this laboratory is in no way better than the earlier method except that it requires less manipulation and the results are more practical for road builders. Table I, on page 13,

[a] A. A. Gilmore. Report on Building Stones of the United States, 1875, p. 8.

[b] J. F. Williams. Annual Report of the Arkansas Geological Survey, 1890, p. 47.

shows the maximum and minimum per cent of water absorbed by each variety of rock tested and has already been considered in connection with the effect of freezing on road materials.

Specific Gravity and Weight Per Cubic Foot.

The specific gravity and weight per cubic foot for all rock samples are calculated from the weights used for determining the absorptiveness of rocks, which are given in Table A of the Appendix.

Test for Hardness.

The laboratory is equipped with a Dorry machine for testing the hardness of materials according to the standard method of the French School of Roads and Bridges. The machine, however, has just been installed and no results have as yet been obtained.

Compression and Tensile Strength Tests.

The laboratory is equipped with a 200,000-pound universal Riehlé testing machine and a 30,000-pound Olsen. Although compression and tensile strength tests do not form part of the routine examination of road materials, they are often of the highest value in special cases.

TESTS FOR PAVING BRICK.

Rattler Test.

The machine for conducting this test is shown in fig. 9. It consists essentially of a rotation drum partially filled with large and small cast-iron blocks or shot. The wearing quality of paving brick is judged by the loss sustained after a sample has been subjected in this drum for one hour to the impact and abrasion of these cast-iron shot. For the first 600 rotations the loss is mainly due to a chipping action which develops the brittleness of the brick; between 1,200 and 1,800 rotations the loss is mainly due to an abrasive action which develops the softness of the brick. During the test any defects of structure, such as planes of separation, will probably result in rupture. The particular form of rattler shown was designed and built at Purdue University, Lafayette, Ind. It is an overhanging rattler, and at the free end there is convenient access to the drum for the purpose of inserting and removing the bricks, an operation which in the ordinary form of rattler necessitates the removal of a slat of the drum. A tight sheet-iron cover prevents the escape of dust. The worn material is caught in a pan, as shown in the illustration.

The rattler is 28 inches in diameter and 20 inches long and has 14 cast-steel slats. It is run at a speed of 30 rotations per minute for 1,800 revolutions. The charge to be placed in the rattler consists of 9 paving blocks or 12 dry bricks, together with 300 pounds of shot made of ordinary machine cast-iron. The shot are of two sizes. The larger size ($2\frac{1}{2}$ by $4\frac{1}{2}$ inches) weigh 7.5 pounds each and have slightly rounded edges; the smaller shot (1.5-inch cubes) weigh about seven-eighths of a pound each. The charge is composed of 75 pounds of the larger and 225 pounds of the smaller size. The individual shot are replaced by new ones when they have lost about one-tenth of their original weight. The loss in weight undergone by a sample of the brick under test at the end of 1,800 revolutions is found by comparing the original weight of the brick with its weight after test. The loss

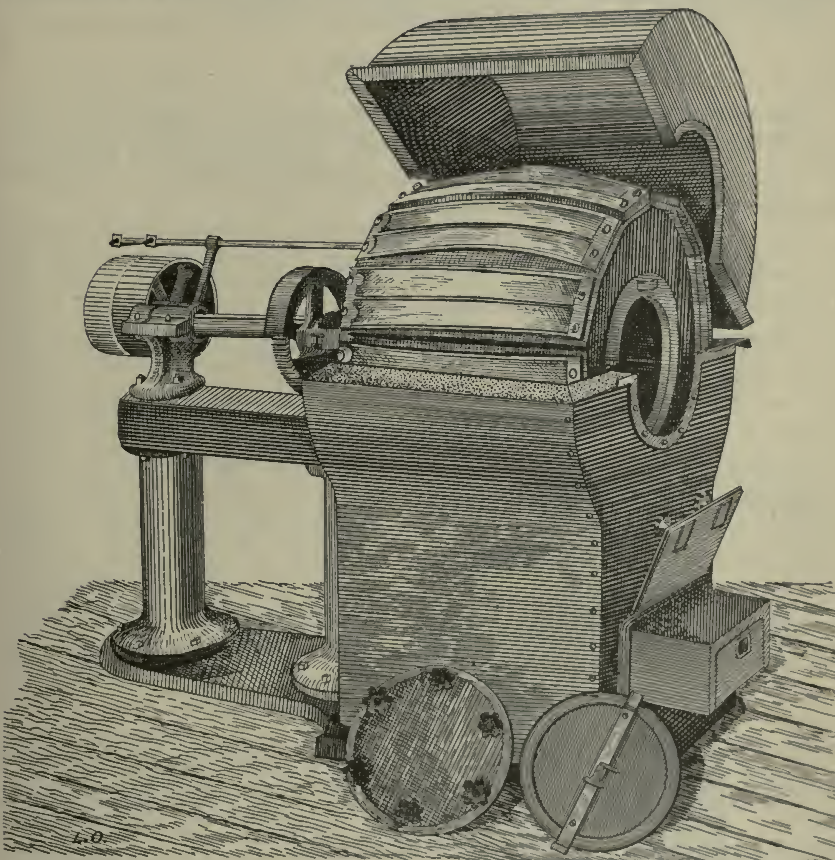

FIG. 9.—Brick rattler.

in per cent of the original weight is the factor determining the quality of the brick. For the best paving brick this loss should not be in excess of 18 per cent. The above conditions are those demanded in the standard specifications recommended by the National Brick Manufacturer's Association.

In order to collect data which will give a knowledge of the degree of variation in the quality of individual brick this laboratory determines the loss of weight of individual brick as well as the average loss of the charge. Furthermore, since the loss during the earlier stages of the test is mainly due to a chipping action and the subsequent loss to the wearing or abrasive action of the charge, both factors of quality are reported, viz, the chipping loss at 400 or 600 rotations and the wearing loss between 1,200 and 1,800 rotations. The form of report for the rattler test is given in the Appendix.

The rattler test for paving brick has won the confidence of engineers after a very searching investigation extending over a number of years. As now conducted, this test is constant in its action and gives valuable evidence concerning the wearing qualities of brick.

Absorption Test.

The absorption test is valuable in determining the degree of heat at which the brick was burnt. It is not, however, practicable to specify a fixed per cent of absorption to which competitive samples of different brands of paving brick must conform.[a]

The absorptiveness of paving brick is determined in this laboratory by immersing in distilled water a brick which has passed through the rattler test and been thoroughly dried. The gain in weight after ninety-six hours' immersion is determined and expressed in percentage of the original weight of the brick. The fact that some paving bricks are covered with an impervious shell makes it desirable to conduct this test on a brick whose interior structure is accessible to water; therefore, only bricks that have been subjected to the rattler test are used. As far as present evidence shows, there is no serious objection to a high rate of absorption on account of danger from disruption of the brick through the action of frost. Defects of internal structure, however, such as internal planes of division due to faulty annealing, present an opportunity for the disruptive action of freezing water. These internal faults of structure are made evident in the rattler test.

Cross-breaking and Compression Tests.

Facilities exist in the laboratory for performing both of these tests according to approved methods on the testing machines already mentioned. The core drill shown in fig. 10 is available for making cylindrical test pieces of 1 or 2 inch diameter from the body of the brick for the compression test. Cross-breaking and compression tests are, however, considered to be of secondary importance and do not furnish as valuable evidence of the quality of the brick as do the rattler and absorption tests.

TESTS FOR CEMENT.

For making physical and mechanical tests on cement a Fairbanks testing machine and other necessary equipment are used. The stand-

[a] Seventeenth Annual Report of the Illinois Society of Engineers and Surveyors, 1902, p. 160.

ard methods adopted by the American Society of Civil Engineers are closely followed. Facilities also exist for the analysis of the raw materials and their actual mixture and manufacture into cement on a laboratory scale. Lack of funds, however, has so far prevented the testing or investigation of cements and concretes except in a desultory way.

CLASSIFICATION OF MATERIALS.

It is most essential that all rocks tested at the laboratory should be analyzed petrographically or chemically, and properly classified, otherwise endless confusion would result.

Petrographic Analysis.

The methods of petrographic examination do not differ essentially from those generally employed. The laboratory is equipped with an exceptionally good microscope of the latest Fuess model, which, besides the usual attachments, is provided with a revolving analyzer in the tube for the determination of very low doubly refracting minerals and a Schwarzmann scale for the measurement of optical axial angles. Another important accessory is the detachable-screw micrometer, movable in the focal plane of the ocular by means of a drum screw, which, with the most powerful objective lens, records a drum interval of 0.000040 mm.

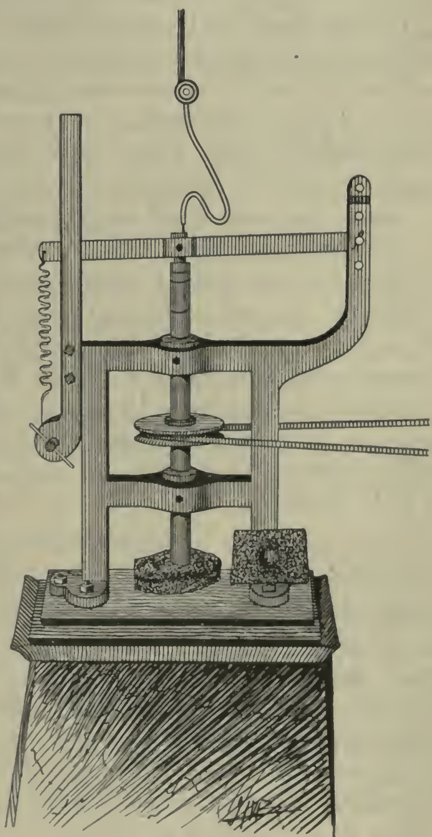

Fig. 10.—Core drill.

A very important feature of the microscopic work is the relative quantitative determination of the mineral components of rock, to accomplish which an ordinary fixed eyepiece having a square field was divided into 100 quadratic areas. With the aid of this cross-line field, each square of which is one one-hundredth of the whole field, the relative proportions of the minerals occupying the field can be readily determined by simply noting the number of squares covered by each mineral in turn. Averages derived from numerous examinations of this kind in various parts of the section indicate the percentage of the different minerals constituting the rock itself.

In describing the character of the material, the origin of the rock, as far as revealed by the microscope, has been observed. Thus rocks with well-defined porphyritic or flow structure, such as rhyolite, andesite, volcanic tuffs, etc., are considered as effusive or volcanic, while deep-seated varieties such as granite, syenite, quartz-porphyry, etc., are described as plutonic or intrusive as the case may be. When the mode of origin is obscure, the general term "igneous" is used. Sandstones, limestones, etc., on the one hand, and quartzites, schists, gneisses, etc., on the other are treated as sedimentary and metamorphic rocks respectively, while disintegrated material such as sands, clays, etc., are classed as sedimentary deposits.

In describing the igneous rocks a very simple classification according to well-recognized types has been best adapted to the requirements of the laboratory. No attempt is made to subdivide these main families except in rare instances where minerals foreign to the normal composition of the rock occur in appreciable quantities. Thus a granite rich in hornblende would be termed hornblende-granite, or a syenite containing much augite, augite-syenite, etc.

Finally the reports under general remarks call attention to the origin of the secondary constituents as well as to the color, texture structure, and other physical properties of the rock specimen likely to be of use to road builders. The tabulated results on all samples examined will be found in Table B of the Appendix. Microphotographs have been made from sections of some of the principal types of rocks examined and some of these photographs, selected to show the characteristic structure of various types, are reproduced in Plates I to V, inclusive.

Chemical Analysis.

The purpose of the chemical analysis of road materials is to supplement the petrographic identification and classification of rocks as well as to supply data which when taken in connection with the physical tests may furnish information as to the value of a given material. The study and chemical examination of clays, marls, etc., has become an important part of the laboratory work, not only because the manufacture of cements, drain tiles, and pipes is indirectly a road-building problem, but also on account of recent efforts to construct practical roads by mixtures of burnt and raw clay in sections of the country where no stone is available. The rapid growth of intelligent interest, which is taking place all over the country, in the problems of road building has brought about a greatly increased demand for laboratory methods of investigation. The number of samples presented for examination and the subsidiary value of the chemical examination in most cases have led to modifications of the ordinary methods of rock analysis which, in the experience of this laboratory, furnish a sufficient degree of accuracy with the minimum expenditure of time.

The number of inquiries received as to the methods used in the chemical analysis of rocks, clays, cements, etc., has shown that in spite of the great number of text books on technical chemical analysis, there is a demand for methods of rock and clay analysis which shall be at the same time practical, rapid, and accurate enough for the purpose in hand.

The methods as given in detail in the Appendix have been tested in the hands of several workers on a large number of samples, and have been found to yield satisfactory results when compared with more complete and accurate work. Analysis is always made on air-dry samples, as the directions usually given in text-books for operating on samples dried at 100° C. invariably lead to bad results, since plastic clays and rock powders reabsorb comparatively large quantities of water from the air after being heated.[a]

By following the scheme of analysis given in the Appendix several analyses can be completed by one man in one working day, provided the fusions have been made on the preceding day and the evaporation for the separation of the silica allowed to go on over night. There is no claim made that these short cuts yield results as accurate as more precise and tedious methods; in fact, any scheme of analysis which divides a gram sample into five aliquot parts is open to criticism, as each determination, with the exception of the silica, has its error multiplied by five. Nevertheless, if the pipette for dividing the solution is accurately standardized to deliver exactly the fifth of the contents of the half-liter flask used, the summation of the complete analysis comes within 0.5 per cent of 100 in the large majority of analyses.

Among the rarer or more unusual elements only manganese and titanium are included in the scheme of analysis. Undoubtedly other elements, such as chromium, barium, strontium, zirconium, lithium, chlorin, and fluorin are present in many rocks and clays, but usually the amounts are so small that for practical purposes they can be ignored. Titanium, on the other hand, is rarely absent and is not infrequently present to the extent of several per cent. Although the effect, if any, of titanium on the properties of clays and cements is not known, it is certainly wrong to report this constituent as alumina, as is nearly always done.

THE APPLICATION OF LABORATORY RESULTS TO PRACTICE.

The proper interpretation and application of the results obtained in the laboratory are quite as important as the general accuracy and appropriateness of the tests themselves. It is probable that many engineers and others interested in the subject of road building who

[a] Cushman. Jour. Am. Chem. Soc., May, 1903.

have found time to examine the question only superficially have misunderstood the bearing and value of road-material testing. In all cases the results obtained in testing materials of construction are of relative rather than absolute value. Even quite a large variation in the results yielded by different test pieces of the same sample should not condemn the practical value of the figures if they are properly applied and interpreted. The necessary qualities of road materials have to be considered from the double standpoint of furnishing a strong, unyielding, well-drained road foundation and a hard, coherent binder surface. In road building the attempt should be made to get a perfectly smooth surface, neither too hard, too slippery, nor too noisy, and as free as possible from mud and dust, these results to be attained and maintained as cheaply as possible. Such results, however, can be achieved only by selecting the material and methods of construction best suited to the conditions.

Given a number of materials for laboratory examination, it is not pretended that an actual practical grade of excellence can be established. On the other hand, if more than one material is available, it is quite possible for the laboratory to point out which one would yield the best results both as to immediate excellence and length of life under known conditions of climate and traffic. Undoubtedly in many cases large sums of money have been wasted in building roads from unsuitable material, which might have been saved by referring the materials to the laboratory. If, for instance, it is desired to know whether an available rock will be useful as a top dressing to form the binder surface, no better method of obtaining preliminary information on the subject is known than to test the cementing value. Undoubtedly some rocks will yield powder from successive test pieces which shows very wide variations in this value under the conditions of the test, but there is at present no difficulty in distinguishing between good and bad material. It is true that before the discovery that certain road materials increase in binding power after being in use for a time some errors were made. A notable, although exceptional, example of this kind was a southern chert from Alabama. The method formerly used of mixing the rock dust with water and immediately molding the briquettes, as previously described in this bulletin, yielded a low cementing value, and the rock was not recommended as a surfacing material if a better one was available. It appears, however, that these southern cherts develop a high binding power under traffic and make excellent roads. Under the present method of conducting the cementation tests—i. e., allowing the dough to stand before molding it, the briquettes of this same chert gave a comparatively high cementing value. It has been impossible, under the pressure of routine work during the current year, to prepare the figures and results of these and many other investigations for publication in this bulletin. These results will be reserved for a special report on the cementing value of road materials, to be published as soon as possible.

It has already been stated that a road material can not be selected, irrespective of the volume and character of traffic and the climatic conditions to which it is to be subjected, without the risk of failure. When the very great cost even of rural highways is considered, it is evident that it is gross negligence not to use every preliminary precaution to guard against expensive mistakes. In order to properly designate the conditions best suited for a particular material it soon became evident that traffic must be classified according to its volume and character. The following five divisions of traffic are therefore made: City (perurban), urban, suburban, highway, and country road. City (perurban) traffic is such as exists on the business streets of large cities, and no macadam road can withstand it. For such a traffic stone and wood blocks, asphalt, brick, or some such materials are necessary. Urban traffic is such as exists on city streets which are not subjected to continuous heavy teaming, but which have to withstand very heavy wear, and require the hardest and toughest macadam rock, or other highly resistant material. Suburban traffic is such as is common in the suburbs of a city and the main streets of country towns. Highway traffic is a traffic equal to that of the main country roads. Country road traffic is that of the less frequented country roads.

This classification is purely arbitrary, but it serves the purpose for which it was intended, and each group can be approximately identified by a road builder. City (perurban) traffic requires the hardest and toughest materials available, having the highest wearing qualities. For urban traffic, such materials as asphalt, brick, wood block, and bituminous macadam are suitable, and if ordinary macadam is used, a rock of the highest hardness, toughness, and wearing qualities is needed. For a suburban traffic the best rock would be one of high toughness but of less hardness than for urban traffic. For highway traffic a rock of medium hardness and toughness is best, and for country road traffic a comparatively soft rock of medium toughness.

To obtain the best results on a macadam road that rock should be selected which would resist the wear of the traffic to which it is subjected to such a degree as to supply just the sufficient amount of binding material to cement the road. Too much or too little wear are alike injurious. The higher the cementing value of the rock the smaller the wear necessary. When a road is first constructed a sufficient amount of binding material must be supplied to cause it to "come down" under the roller or traffic. If the subsequent traffic is not sufficient to wear off the requisite amount of binder to replace that carried off by wind and rain the road "ravels." If the traffic wears off an excess of binding material, mud and dust result. In either case the material is not well suited to the conditions. In the first case a softer rock should be used; in the latter, a harder, tougher rock, and in all cases a rock of high binding power. For example, if a country road or city park way, where only a light traffic prevails, were built of a very hard and tough rock with a high cementing value, neither the best results nor the cheapest, if a softer rock were available, would be obtained. Such a rock would so effectively resist the wear of a light traffic that the amount of fine dust worn off would be carried away by wind and rain faster than it would be supplied by wear. Consequently the amount of binder produced by wear would be insufficient, and if not supplied from some other source the road would soon go to pieces. The first cost of such a rock would in most instances be greater than that of a softer one, and the necessary repairs resulting from its use would also be expensive.

It has already been pointed out in a former publication[a] from this laboratory that rocks belonging to the same species and having the same name, but coming from different localities, vary from each other in their physical road-building properties almost as much as they do from rocks of distinct species. Wide variation also occurs in the mineral composition of rocks of the same species, as well as in the size and arrangement of their crystals. It is impossible, therefore, to classify rocks for road building by simply giving their specific names. It can be said, however, that certain species of rocks possess in common some road-building properties. For instance, the trap[b] rocks as a class stand heavy traffic well, as they are hard, tough, usually have binding power, and are therefore frequently spoken of as the best rocks for road building. This, however, is not always true, for numerous examples can be shown in which trap rocks having the above properties in the highest degree have failed to give good results on light-traffic roads. The reason trap rock has gained so much favor with road builders is because a large majority of macadam roads in our country are built to stand an urban traffic, and the traps stand such a traffic better than any other single class of rocks. There are, however, other rocks that will stand an urban traffic perfectly well, and there are traps that are not sufficiently hard and tough for a suburban or highway traffic. The granites are generally brittle and many of them do not bind well but there are a great many which when used under proper conditions make excellent roads. The felsites are usually very hard and brittle and many

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[a] The Selection of Materials for Macadam Roads, Yearbook of the Department of Agriculture, 1900.

[b] This term is derived from the Swedish word *trappa*, meaning steps, and was originally applied to the crystallized basalts of the coast of Sweden, which much resemble steps in appearance. As now used by road builders, it embraces a large variety of igneous rocks, chiefly those of fine crystalline structure and of dark-blue, gray, and green colors. They are generally diabases, diorites, trachytes, and basalts.

have excellent binding power, some varieties being suitable for the heaviest macadam traffic. Limestones vary greatly but generally bind well; they are soft and frequently improve under traffic. Quartzites are almost always very hard, brittle, and have very low binding power. The slates are usually soft, brittle, and lack binding power.

When samples of rock are received at the laboratory without a request for specific information, the method of procedure is as follows: The samples are subjected to the tests already enumerated, and the results are classified and compared with those of like value and known worth in practice. These results, together with a statement of the particular group of traffic to which the materials are best suited are forwarded to the sender[a]. When samples are sent for the purpose of ascertaining which is best suited for a particular road, the sender is requested if possible to supply the laboratory with a census of the traffic or, if this is impracticable, to state what class of traffic passes over the road. The tests are then made and the results classified and compared as in the previous case. Full information regarding the climatic conditions is obtained from the Weather Bureau and that material is selected which the results indicate to be best suited to the conditions. Allowance is always made for at least a 15 per cent increase in the volume of traffic due to the improved conditions, if the road is to be macadamized for the first time.

As time goes on and the behavior of these tested materials is studied and records of traffic are accumulated the value of the laboratory tests will constantly increase. Cooperation among the increasing number of laboratories in the country is much needed and uniform methods of testing should be adopted. The American Society for Testing Materials has been asked to appoint a committee to investigate the whole subject of the testing of road materials with a view to bringing the work of the various and widely separated laboratories under standard conditions. As soon as the rapidly growing mass of data on this subject is thus made uniform and comparable it will be of the very highest value.

Those who are familiar with the problems of rural road building know the great difficulty of selecting among the available materials for a particular road the one which will give the best results for the least cost of construction and maintenance. There are, undoubtedly, practical road builders whose judgment on the road-making quality of a rock is excellent, but experience with materials of construction in general has proved that it is wise and economical to test the physical properties of materials before entering on the expenditure of large sums of money. Bridge building would not have become the high art that it has had not the careful and systematic testing of materials put

[a] See forms on page 75 of the Appendix.

into the hands of the engineer preliminary data on which to base his calculations and estimates. It is hoped that before long intelligent cooperation will make this true of road building. To this end the laboratory has decided on the following plan to govern its future work. It will require a few years for the completion of the plan, but by following it until a better one is evolved the usefulness of the laboratory should constantly increase.

As it is impossible to accurately judge the quality of a road material unless the conditions of climate and traffic on the particular road where it is to be used are known, it is intended to secure such data as far as possible. For this purpose a form[a] for making a census of the volume and character of traffic on any road has been prepared. The cost of such a census is trifling when the total cost of the road is considered, and the observations may be made by anyone living within view of the road. When enough of these records have been accumulated, the traffic of a road may be expressed by a number, if a unit and standard scale are agreed upon to suit the average conditions of the country as has been done in France. The maximum, minimum, and mean conditions of temperature, rainfall, and wind velocity for any locality can be obtained from the Weather Bureau, and also classified according to a similar scale. When a large number of standard results of different tests have been accumulated and compared with the results of practice, it will be possible to classify them into five groups to correspond to the five subdivisions of traffic. Thus, when a test sample is received at the laboratory, together with a census of the traffic on the road to be constructed, the traffic and climate will be placed in their proper groups and the hardness, toughness, resistance to wear, cementing value, weight per cubic foot, and absorptiveness will each be graded according to the same standard scale. By this method the best available material for any road can be selected with a high degree of accuracy, for the proposed classification will be based on the observations of practice as well as on laboratory tests. Such results can not fail to be of the highest value to the road engineer.

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[a] See page 77, Appendix.

APPENDIX.

METHODS OF CHEMICAL ANALYSIS ESPECIALLY ADAPTED TO THE RAPID EXAMINATION AND CLASSIFICATION OF ROAD MATERIALS.

I. COMPLETE ANALYSIS.

A.—*Substances mainly insoluble in hydrochloric acid.*

The sample for analysis is powdered on the agate mortar until all indication of gritty particles has disappeared. The sample is then spread in a thin layer between filter papers and allowed to stand overnight to air dry.

Exactly 1 gram is weighed into a large platinum crucible and mixed with from 4 to 6 grams of a fusing mixture, which is made by grinding together in a porcelain mortar 50 grams sodic carbonate, 50 grams potassic carbonate, and 2 grams of potassic nitrate.

The crucible is heated up gradually over an ordinary Bunsen flame until all bubbling has ceased and the contents are in a state of quiet fusion, when the blast lamp is applied at its maximum temperature for ten minutes. The liquid fusion is immediately poured into a platinum dish floating in a basin of water. The material still adhering to the crucible is dissolved in dilute hydrochloric acid with the usual precautions, and after the removal of the crucible and cover the fused button is added. After solution is complete the cover is removed from the casserole and the contents evaporated to dryness as quickly as possible on the steam bath. As dryness is approached the lumps are broken up with a button-ended stirring rod, and the heating continued until the residue has the consistency of a dry powder. This residue is taken up with dilute hydrochloric acid and the silica filtered and washed. The procedure at this point depends upon the degree of accuracy desired, and two methods are accordingly suggested.

(1) *Accurate method.*—The filtrate from the silica is again evaporated to complete dryness, taken up with dilute hydrochloric acid, and the small amount of silica filtered out, washed, and united with that obtained by the first filtration. After burning off the paper the white silica is blasted at the highest temperature of the blast lamp for fifteen minutes, cooled, and weighed. It is then treated with an excess of hydrofluoric acid and two or three drops of strong sulphuric acid, evaporated carefully to dryness, and finally blasted. The true per cent of silica present is shown by the loss in weight. The weighed crucible containing the small residue is preserved for the ignition later on of the main portion of the alumina, together with the oxids of iron, phosphorus, and titanium, but as the filtrate is divided into aliquot parts, only one-fifth of the weight of the residue applies as a correction.

(2) *Rapid approximate method.*—One evaporation to complete dryness on the water bath is made, care being taken to break up the lumps of the residue by stirring and rubbing with a flat-end glass rod as the point of dryness is approached. The residue, which should be quite dry and powdery, is taken up with hydrochloric acid and the

silica filtered, washed, and burned white over an ordinary Bunsen flame. The error resulting from a single evaporation on the water bath is in most cases very nearly counterbalanced by the error introduced by omitting the blasting, while the saving in time is very considerable. The slight amount of silica which remains in solution is carried down later with the iron and alumina, and serves to counterbalance the small quantity of aluminum phosphate and alumina almost always found in the silica.

Whichever of the two procedures as given above has been followed, the filtrate from the silica is transferred to a 500 cc graduated flask, diluted to the mark and very thoroughly shaken. This is solution A. A 100 cc pipette which has been carefully calibrated to divide the contents of the flask into exact fifths under standard conditions is used for dividing the solution into aliquot parts. Manganese usually shows itself in the green color which it imparts to the fusion, and a slight pinkish color which can be observed when the fusion is first treated with hydrochloric acid. A 100 cc portion having been transferred to a beaker, its treatment will depend upon whether or not manganese is present.

(1) *When manganese is present.*—Add a solution of sodic carbonate until one or two drops in excess have produced a permanent precipitate. Clear with one drop of concentrated hydrochloric acid. Dilute to 200 cc, add ten drops of glacial acetic acid and 2 grams of crystallized sodic acetate. Heat to boiling and boil three minutes. Allow to settle and filter hot. Wash a little with 2 per cent sodium acetate solution, dissolve the precipitate in an excess of hydrochloric acid, and reprecipitate with ammonia—filter, wash, ignite, and weigh. The two filtrates are combined and boiled for some time with additions of bromin water until the precipitation of manganese dioxid is complete. The precipitate is ignited over the ordinary Bunsen flame and weighed as Mn_3O_4. The filtrate from the manganese dioxid precipitate which contains calcium and magnesium is put on the steam bath for concentration while other portions of the analysis are proceeded with.

(2) *When manganese is absent.*—Ammonia is added in slight excess, the solution boiled for two minutes and filtered hot, using the pump. Unless the precipitate is a small one, another precipitation is necessary. The precipitate is dissolved in hydrochloric acid in the same beaker, reprecipitated with ammonia, filtered, washed with hot water, blasted, and weighed. If necessary the combined filtrates are placed on the steam bath for concentration. The paper containing the precipitate is transferred wet to a weighed crucible. If the accurate method has been used, there will be a weighed crucible ready to receive it. The paper and contents are rapidly dried by keeping the crucible moving over a free flame, the paper is burned off and the precipitate finally blasted and weighed. This weight represents ferric oxid, alumina, titanium oxid, and phosphoric anhydrid.

TOTAL IRON.

One hundred cubic centimeters of solution A is poured directly through a reductor and followed by 150 cc of distilled water. The clear, colorless solution is transferred to a beaker, and to it is added 50 cc of dilute sulphuric acid and finally 5 cc of a 20 per cent solution of manganous sulphate. The contents of the beaker are immediately titrated with standard permanganate solution. The titration with bichromate is not nearly so rapid as the titration with permanganate and with very small amounts of iron the end point can not be accurately distinguished. A large number of trials has shown that this direct method of titration in the presence of hydrochloric acid is quite as accurate as those which call for an evaporation with sulphuric acid or a preliminary precipitation with ammonia, filtration, and re-solution in sulphuric acid. A permanganate solution is made by dissolving 1.975 grams in a liter. One cubic centimeter of this solution equals 0.005 gram ferric oxid (Fe_2O_3). The reductor used is practically the same as the simple device described by Shimer.[a] The tube has an internal diameter of three-eighths of an inch, and is 20 inches long. It is drawn out and cut off at its lower extremity with an opening of 1 mm diameter. One inch of coarse sand is placed at the bottom and the rest of the tube is filled with amalgamated zinc. The ordinary B and A "iron free" granulated zinc is moistened with dilute sulphuric acid and a little clear mercury stirred in. Suction is applied and regulated so that 60 cc of solution passes through the reductor in five minutes. The washing is allowed to proceed more rapidly. Blanks are run to determine the constant correction for the reductor.

TITANIUM.

To 100 cc of solution A, in a porcelain evaporating dish, 10 cc of strong sulphuric acid is added and the solution evaporated on the steam bath until the hydrochloric acid is expelled and the sulphuric acid solution has little or no yellow color. After slight dilution the solution is filtered into a 100 cc graduated cylinder, 2 cc of pure 3 per cent hydrogen peroxid[b] added, and the solution diluted to 50 cc. In another graduated cylinder containing about 40 cc of water, 2 cc of 3 per cent peroxid is added and then gradually a standard solution of titanium run in from a burette until the colors match, when the solutions are looked at through the same depth of column. The standard solution used in this laboratory is made up so that 1 cc equals 0.0002 gram of titanium oxid (TiO_2). The standard is made up by roughly weighing out somewhat more than the right amount of some titanium salt or compound, and after getting it into solution standardizing it by gravimetric analysis, subsequent dilution, and reanalysis.

PHOSPHORIC ACID.

The volumetric method based upon that adopted by the Association of Official Agricultural Chemists is used for the determination of phosphoric acid. The following solutions are prepared:

PREPARATION OF REAGENTS.

(1) *Molybdic solution.*—One hundred grams of molybdic acid are dissolved in 417 cc of ammonia, specific gravity 0.96, and the solution thus obtained poured into 1,250 cc of nitric acid, specific gravity 1.20. The flask in which the mixture is made is kept cool by immersion in water until the reaction is completed. The mixture is kept in a warm place for several days, until a portion heated to 40° C. deposits no yellow precipitate, when the solution is decanted and preserved in a glass-stoppered bottle.

(2) *Standard potassium hydroxid solution.*—This solution is made up to contain 3.6342 grams of potassium hydroxid to the liter. It is prepared by diluting 64.76 cc of normal potassium hydroxid, which has been freed from carbonates to 1 liter. One cubic centimeter is equal to 0.2 mg of phosphoric acid (P_2O_5).

(3) *Standard nitric acid solution.*—The strength of this solution is the same as the standard alkali solution, and is determined by titrating against that solution, using phenolphthalein as indicator.

(4) *Phenolphthalein solution.*—One gram of phenolphthalein is dissolved in 100 cc of alcohol.

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[a] Jour. Amer. Chem. Soc., 21: 723.

[b] Mere traces of hydrofluoric acid, either in the peroxid or the titanium solution, render this method inexact, hence care should be exercised as to the character of the peroxid, which, as sold in the market, often contains fluorin. (Hillebrand, Bul. U. S. Geol. Sur. 176, p. 68.)

DETERMINATION.

One hundred cubic centimeters of solution A is put into an Erlenmeyer flask, made slightly alkaline with ammonia and then again acidified with nitric acid. About 10 grams of dry ammonium nitrate is added and the solution heated to 60° C. Twenty-five cubic centimeters of the molybdate solution is then poured into the flask, a smooth, tightly fitting rubber stopper inserted, and the contents of the flask vigorously shaken for five minutes. After allowing a short time for the yellow precipitate to settle it is filtered and washed five or six times with a 3 per cent solution of potassium nitrate. The precipitate and filter is transferred to a beaker, dissolved in a small excess of standard alkali, a few drops of phenolphthalein added, and the solution titrated with the standard nitric acid.

Lime.

The concentrated filtrate from the iron, alumina, etc., is made decidedly ammoniacal and brought to a boil, a sufficient quantity of saturated solution of ammonium oxalate is then added, avoiding a large excess. Boiling is continued for a few minutes when the beaker is immediately set into a dish of cold water. The precipitate settles rapidly, and is at once filtered, using a platinum cone with the pump, and washed thoroughly with hot water. The filtrate is reserved for the determination of the magnesia. The filter paper containing the washed calcic oxalate is lifted from the cone and opened inside a beaker. By means of a well-directed stream of a wash bottle all precipitate can be washed off the paper. Fifty cubic centimeters of dilute sulphuric acid is then allowed to run over the paper into the beaker, more water is added, the solution heated to about 60° C., and immediately titrated with standard permanganate solution. The lime factor is exactly one-half the iron factor of the permanganate solution.

Magnesia.

The filtrate from the lime determination is made slightly acid with hydrochloric acid and 30 cc of a concentrated solution of disodic phosphate added. It is then evaporated down to a bulk not exceeding 150 cc, transferred to an Erlenmeyer flask, and after cooling ammonia is added gradually with shaking until the reaction is strongly alkaline. The flask is stoppered with a smooth rubber stopper and shaken vigorously for five minutes. By this treatment the precipitate will usually be ready to filter inside of an hour. The filtrate should always, however, be preserved over night to make sure that no more precipitate appears. The precipitate is collected either on paper or a weighed Gooch crucible, burned, blasted, and weighed as magnesium pyro-phosphate ($Mg_2P_2O_7$), which multiplied by 0.3619 equals magnesium oxid (MgO).

Sulphuric Acid.

Sulphur occurs in rock and clays usually as sulphids, more rarely as sulphates. The quantities are nearly always small, and in the cases where they are not the microscopic examination has disclosed the fact. It is customary in rock and clay analysis to report sulphur as SO_3, and that method has been followed.

The remaining 100 cc of solution A is heated to boiling, and a few cubic centimeters of a solution of barium chlorid added, and the boiling continued for five minutes. When the precipitate is settled it is collected on a paper or on a weighed Gooch crucible, washed with hot water, ignited, and weighed as barium sulphate ($BaSO_4$), which multiplied by 0.3430 equals SO_3.

Ferrous Iron.

The determination of iron in the ferrous state is an important matter in connection with the analysis of clays. Fairly satisfactory determinations can be secured by boiling 1 gram of the sample with hydrofluoric and sulphuric acids in a large covered platinum crucible. After boiling five minutes the solution is cautiously diluted and at once titrated with potassium permanganate.

Potassium and Sodium Oxid. (K_2O, Na_2O.)

One-half gram of the very finely ground powder is mixed with its own weight of pure ammonium chlorid, and the two thoroughly ground together. About 4 grams of pure calcic carbonate is added, and the grinding continued until an intimate mixture is made. This mixture is transferred to a J. Lawrence Smith tubular crucible [a] and the mortar rinsed with a little extra calcic carbonate. The crucible is capped and placed in a fire-clay furnace and heated for about ten minutes by a low flame. As soon as no more odor of ammonia is perceptible it is heated by the full heat of two Bunsen burners for three-quarters of an hour. After cooling, the sintered mass usually detaches from the crucible but it may be loosened with hot water. The mass is transferred to a platinum dish, and digested with hot water until completely disintegrated. The solution is filtered into a beaker and the residue washed, a few drops of ammonia and ten of a saturated solution of ammonia carbonate added, the solution filtered into a platinum dish, and the residue washed thoroughly. The filtrate is evaporated to dryness, and the residue heated at a dull red heat until the ammonia salts are expelled. After cooling, the residue is taken up with a little water, and a few drops of ammonia and ammonic carbonate added to make sure that all the calcium has been precipitated. The solution is filtered on a small filter into a weighed platinum dish, and the precipitate and paper washed with hot water. A few drops of dilute hydrochloric acid are added and the clear solution evaporated to dryness. The ammonia salts are then expelled by very careful heating to a dull red heat, and weighed as potassium and sodium chlorid ($KCl+NaCl$).

The mixed salts are dissolved in water and an excess of platinic chlorid added to the solution. After evaporating nearly to dryness on a steam bath, 20 cc of alcohol is added and allowed to stand one hour. The precipitate is filtered on a weighed Gooch crucible, washed with alcohol, dried at a low heat in an air bath, and weighed as potassium platinic chlorid (K_2PtCl_6), which multiplied by 0.1940 gives potassium chlorid (KCl).

Water.

For the determination of water, the ordinary method of loss on ignition is not depended upon except in cases in which it is quite certain that carbon dioxid and oxidizable or reducible matter are absent. A sample of about 2 grams of the air-dried powdered material is weighed into a platinum boat, which is placed inside a hard glass combustion tube and strongly ignited in a current of dry air. The expelled water is collected in a sulphuric acid weighing tube, which is connected by a very short piece of rubber tubing to the drawn-out end of the combustion tube.

B.—*Substances mainly soluble in hydrochloric acid.*

In the cases of limestones and dolomites which contain less than 10 per cent of insoluble matter the weighed sample is treated with dilute hydrochloric acid, and the solution, after the filtration of the insoluble residue, is treated exactly as under A, "substances mainly soluble in hydrochloric acid." Whether or not the insoluble residue will require fusion and separate analysis will depend upon the objects of the analysis. Calcareous clays, which are largely insoluble, are best treated as under A, and fused at once.

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[a] Bul. U. S. Geological Survey 176; 97.

II. RATIONAL ANALYSIS.

In the study of clays for various purposes a rational analysis is often called for, and in spite of its great inaccuracy undoubtedly gives results which are of some practical value. The method as given by Meade,[a] which is convenient and rapid, is used with some slight modification in this laboratory.

Heat 1.25 grams of the finely ground sample with 15 cc of concentrated sulphuric acid to near the boiling point of the acid and digest for five hours at this temperature. Cool, dilute, and filter. Wash and ignite the residue to a constant weight, called A. After weighing, brush the residue, which consists of silica, present as sand and undecomposable silicates and silica from the decomposition of the silicates of alumina, into an agate mortar, grind very finely, and weigh 0.5 gram of it into a platinum dish containing 50 cc of boiling caustic potash solution (1.125 sp. gr.). Boil for five minutes, filter, wash first with hot water and then with water containing a little dilute hydrochloric acid, and then again with hot water, dry and ignite to a constant weight. Call this weight B. Multiply A by 0.4 (to correct the 1.25 grams of clay used to correspond to the 0.5 gram of the residue taken for treatment with caustic potash solution) and subtract B from the product. Multiply the difference by 200 to obtain the per cent of silica combined with alumina in the clay. This deducted from the total silica found by analysis gives the silica as sand and undecomposable silicates.

TABLE A.—*Results of laboratory tests.*

[The starred figures are the results obtained by the new method, see page 42.]

Serial No.	Locality.	Name of material.	Coefficient of wear.	Per cent of wear.	Weight in pounds per cubic foot.	Pounds of water absorbed per cubic foot.	Cementing value.
	ALABAMA.						
388	Birmingham, Jefferson County	Chert					*31
389	.....do	.....do					*84
391	.....do	.....do	3.9	10.2	162.5	1.3	*127
392	.....do	.....do	4.9	8.2	159.4	2.2	*113
393	.....do	.....do	4.2	9.6	151	3.4	*58
394	.....do	.....do					*102
395	.....do	Blast-furnace slag	5.2	7.6	168.8	.6	[b]137
442	.....do	Dolomite	7.1	5.7	168.8	1.3	14
443	.....do	Chert					*390
425	Farmsdale, Hale County	Calcareous clay	2.1	19.1			1,489
426	.....do	Limestone	2.3	17.4	162.5	2.6	111
390	Tuscaloosa, Tuscaloosa County	Gravel					11
724	Tuskegee, Macon County	.....do					*400
725	.....do	.....do					*75
	ARKANSAS.						
651	Batesville, Independence County	Gravel					17
652	.....do	.....do					8
739	Fort Smith, Sebastian County	.....do					*34
740	.....do	.....do					*500
741	.....do	.....do					*21
742	.....do	Sandstone	10	4	156.3	1.4	*90
743	.....do	.....do	10.7	3.7	162.5	1.3	*79
438	Hot Springs, Garland County	Chert	3.6	11.1	162.5	.4	*10
	CALIFORNIA.						
578	Los Angeles, Los Angeles County	Granite	2.7	14.8	162.5	.9	4
538	San Jose, Santa Clara County	Chert			156.3	1.8	*13

[a] Examination of Portland Cement. Chem. Pub. Co., 1901.
[b] High cementing value for slag.

TABLE A.—*Results of laboratory tests*—Continued.

[The starred figures are the results obtained by the new method, see page 42.]

Serial No.	Locality.	Name of material.	Coefficient of wear.	Per cent of wear.	Weight in pounds per cubic foot.	Pounds of water absorbed per cubic foot.	Cementing value.
	COLORADO.						
398	Lakeshore, Hinsdale County	Rhyolite	5	8.1	175	4.2	577
399	Capitol City, Hinsdale County	Brecciated felsite.	11.9	3.4	156.3	3	12
406	Lakeshore, Hinsdale County	Rhyolite tuff	4.1	9.7	156.3	2.9	513
407	Lake City, Hinsdale County	Andesite	11.5	3.5	162.5	1.9	35
408	do	do	6.3	6.4	162.5	1.9	14
409	do	Diorite (trap)	12.5	3.2	168.8	1	18
396	do	Rhyolite breccia	7	5.7	156.3	2.5	327
397	Sherman, Hinsdale County	Granite	4.6	8.7	162.5	.4	39
	CONNECTICUT.						
354	Ansonia, New Haven County	Basalt	19.2	2.1	189.3	.6	10
349	Branford, New Haven County	Diabase (trap)	11.5	3.5	175.1	.8	49
467	Meriden, New Haven County	do	16.9	2.4	181.3	.7	91
	FLORIDA.						
701	Tampa, Hillsboro County	Calcareous clay	......	......	......	......	*4,000+
702	do	Dolomite	2.2	18.6	162.5	4.8	*94
	GEORGIA.						
422	Atlanta, Fulton County	Hornblende gneiss	10.2	4	187.5	.1	3
419	Augusta, Richmond County	Gneiss	15.7	2.6	162.5	.3	8
417	Bartow County	Dolomite.	5	8	178.1	.7	17
583	Canton, Cherokee County	Eclogite	13.8	2.9	231.3	.1	3
424	Chickamauga, Catoosa County	Limestone	7.1	5.7	168.8	.1	99
415	Coweta County	Olivine diabase (trap).	17.3	2.3	193.8	.2	2
421	Lithonia, Dekalb County	Granite	8.3	4.8	168.8	.1	2
416	New Elberton, Elbert County	do	13.1	3	168.8	.1	2
420	Roberts Station, Jones County	Olivine diabase (trap).	15.2	2.6	187.5	.3	6
698	Savannah, Chatham County	Gravel	......	......	......	......	*233
699	do	do	......	......	......	......	*176
423	Stone Mountain Station, Dekalb County	Granite	7.5	5.3	162.5	.1	13
468	Toccoa, Habersham County	Gneiss	7.7	5.2	162.5	.2	2
413	Walker County	Limestone	10.6	3.8	162.5	3.5	74
414	do	Chert	1.4	27.9	143.7	3.3	*12
418	do	do	2.5	16.4	184.4	3.7	*35
	ILLINOIS.						
716	Chicago, Cook County	Dolomite	9.1	4.4	168.8	.6	*18
756	do	do	6.9	5.8	168.8	.8	*28
451	Dixon, Lee County	Dolomite gravel	......	......	......	......	9
437	Elco, Alexander County	Novaculite (chert)	6.8	5.9	153.6	3.3	72
584	do	do	14.6	2.7	151.0	4.1	*15
465	Forreston, Ogle County	Gravel	......	......	......	......	14
454	Kenney, Dewitt County	do	......	......	......	......	16
452	Menominee, Jo Daviess County	Limestone	3	13.1	168.8	1.8	27
450	Ullin, Pulaski County	do	7.2	5.6	156.3	3.3	127
	INDIANA.						
540	Bicknell, Knox County	Dolomitic limestone.	10.1	4	168.8	.9	23
515	Freelandville, Sullivan County	Limestone	10.6	3.8	171.8	.7	38
588	do	Dolomite	16.1	2.5	175	1.3	36
456	Merom, Sullivan County	Gravel	......	......	......	......	10
719	North Vernon, Posey County	Dolomite	......	......	162.5	2.2	......
516	Spencer, Owen County	Limestone	13	3.1	168.8	.9	166
	IOWA.						
383	Butterville, Tama County	Limestone	1.8	21.9	162.2	3.2	22
557	Mason City, Cerrogordo County	Clay	......	......	......	......	250
438	Montour, Tama County	Limestone	5.9	6.8	163.1	1.7	129
455	Peosta, Dubuque County	Dolomite	3.4	11.6	156.3	3.3	32
462	Raymond, Blackhawk County	do	8.9	4.6	168.8	.7	161

TABLE A.—*Results of laboratory tests*—Continued.

[The starred figures are the results obtained by the new method, see page 42.]

Serial No.	Locality.	Name of material.	Coefficient of wear.	Per cent of wear.	Weight in pounds per cubic foot.	Pounds of water absorbed per cubic foot.	Cementing value.
	KENTUCKY.						
446	Lexington, Fayette County	Limestone	6.4	6.2	168.8	.8	58
447	do	do	11.9	3.4	162.5	3.5	56
457	Kuttawa, Lyon County	Sandstone	2.2	17.8	151	8.2	55
461	Cedar Bluff, Caldwell County	Limestone	8.9	4.5	140.7	3.1	80
	MARYLAND.						
759	Baltimore, Baltimore City	Clay					*60
760	do	do					*35
580	Fort Washington, Prince George County.	Gravel					2
487	Frederick, Frederick County	Limestone	6.6	6	168.8	.1	26
427	Cumberland, Allegany County	Sandstone	4.9	8.2	125	9.4	44
428	do	Calcareous shale	2.5	16.2	168.8	1.9	380
429	do	Limestone	3.4	11.7	165.6	1.6	133
430	do	do	3	13.4	168.8	1.7	143
363	Dickerson, Montgomery County	Diabase (trap)	14.2	2.8	186.6	.1	60
343	Frederick, Frederick County	Dolomite	8.9	4.5	176.6	.3	32
439	do	Limestone	6.8	5.9	163	.2	33
	MASSACHUSETTS.						
367	Brookline, Norfolk County	Metamorphic slate.	8.5	4.7	175.6	.5	151
368	do	Rhyolite	22.9	1.8	178.1	.06	24
369	do	Diabase	18.9	2.1	179.6	.4	9
718	Quincy, Norfolk County	Chlorite schist	7.9	5.1	181.3	.1	*28
611	Salem, Essex County	Augite diorite (trap).	14.7	2.7	187.5	.3	18
444	Taunton, Bristol County	Gravel			168.8	.5	13
445	do	Granite	9.7	4.1	168.8	1.5	13
411	Webster, Worcester County	Schist	6.4	6.3	175	.3	18
517	Westfield, Hampden County	Diabase (trap)	30.7	1.3	187.5	.5	76
386	Winchester, Middlesex County	do	6.4	6.3	200.6	.8	21
	MISSISSIPPI.						
460	Brookhaven, Lincoln County	Gravel					16
464	Sardis, Panola County	do					58
453	Stonington, Jefferson County	Sandstone	1.3	31.8	131.2	11.6	53
	MISSOURI.						
351	Gumbo, St. Louis County	Gravel					12
	NEBRASKA.						
360	Bluesprings, Gage County	Chert	6.9	5.8	160.6	1.3	*102
	NEW HAMPSHIRE.						
370	Hanover, Grafton County	Granite	12.6	3.2	165.6	.2	3
371	do	Schist	12.3	3.3	194.1	.2	32
372	Lebanon, Grafton County	Hornblende schist	9.9	4	189.7	.4	25
373	do	Biotite schist	6.7	5.9	169.1	.5	49
	NEW JERSEY.						
357	Chimney Rock, Somerset County	Basalt	23.6	1.7	186.3	.1	72
720	Gladstone, Somerset County	Shale			156.3	4.8	*985
387	Lambertville, Hunterdon County	Gabbro (trap)	14.3	2.8	183.7	.1	131
405	Middle Valley, Hunterdon County	Diabase (trap)	23.8	1.7	187.5	.1	19
341	Millville, Cumberland County	Gravel					1,680
350	New Providence, Union County	Diabase (trap)	23.6	1.7	186.3	.4	19
478	Wanaque, Passaic County	Peridotite	11.1	3.6	209.4	.3	3
566	Shady Side Quarries	Diabase (trap)	19.7	2	184.4	.5	38
637	Somerville, Somerset County	Basalt tuff	2.4	16.6	147.5	6.4	6
669	do	do	4.3	9.3	151	5.7	14

TABLE A.—*Results of laboratory tests*—Continued.

[The starred figures are the results obtained by the new method, see page 42.]

Serial No.	Locality.	Name of material.	Coefficient of wear.	Per cent of wear.	Weight in pounds per cubic foot.	Pounds of water absorbed per cubic foot.	Cementing value.
	NEW YORK.						
404	Bellona, Yates County	Limestone	7.5	5.3	168.8	.1	55
356	Brockport, Monroe County	....do	8.9	4.5	169.4	.3	9
400	Canandaigua, Ontario County	....do	8.8	4.6	168.8	.2	54
344	Deerpark, Orange County	Sandstone	.....	.....	.....	.....	54
382	....do	Shale	8.6	4.7	166.3	1.4	62
346	Geneva, Ontario County	Limestone	13.9	2.9	164.1	1.2	8
347	....do	....do	8.8	4.5	170.9	.2	14
340	Hudson, Columbia County	....do	7.6	5.3	169.7	.5	95
385	....do	Slate	5.8	6.9	169.4	.4	202
410	Leroy, Genesee County	Flint	5.5	7.2	162.5	.2	31
532	Littlefalls, Herkimer County	Gneiss	20.7	1.9	168.8	.3	2
732	North Leroy, Genesee County	Limestone	8.5	4.7	168.8	.1	*138
733	....do	....do	7.9	5.1	162.5	.4	*74
335	Rockland Lake, Rockland County	Diabase (trap)	13.2	3	192.5	.5	110
470	Tomkins Cove, Rockland County	Dolomite	6.7	5.9	168.8	.3	*80
	NORTH CAROLINA.						
514	Ashboro, Randolph County	Felsite	21.3	1.9	168.8	.02	2
469	Asheville, Buncombe County	Hornblende schist	7.1	5.7	200	.2	6
627	....do	Granite	18.6	2.2	168.8	.2	6
628	....do	Diorite	17.4	2.3	181.3	.2	1
705	....do	Hornblende schist	11	3.6	193.8	.5	*7
434	Concord, Cabarrus County	Granite	21.7	1.8	162.5	.3	3
435	....do	Mixed stone	4.6	8.7	.....	.....	12
436	....do	Granite	7	5.7	168.8	.2	2
513	....do	Syenite	14.4	2.8	168.8	.3	2
431	Elm City, Wilson County	Granite	14.2	2.8	165.6	.4	3
539	Fayetteville, Cumberland County	Gravel	.....	.....	.....	.....	43
504	Hot Springs, Madison County	Dolomite	9.5	4.2	181.3	.1	2
535	Morganton, Burke County	Basalt	20.3	2	187.5	.2	2
380	Newbern, Craven County	Clay	.....	.....	.....	.....	45
381	....do	Limestone	1.2	34.2	138.1	1.9	79
366	Pinehurst, Moore County	Gravel	.....	.....	.....	.....	24
432	Wilson, Wilson County	Granite	6.2	6.4	162.5	.4	9
433	....do	....do	7.2	5.6	159.4	.2	20
401	Wilmington, New Hanover County	Conglomerate	3.2	12.7	156.3	2.5	125
402	....do	Limestone	4	9.9	147.4	2.7	127
403	....do	....do	.....	.....	.....	.....	110
	OHIO.						
663	Columbus, Franklin County	Limestone	6	6.7	159.4	3.2	12
664	....do	....do	5.8	6.9	162.5	1.5	41
666	....do	....do	10.6	3.8	156.3	2.6	58
665	....do	Dolomite	7	5.7	159.4	2.7	10
582	East Liberty, Stone County	Dolomitic limestone.	10.6	3.8	175	.8	28
707	Kirtland, Lake County	Fieldstone (erratics.)	8	5	.....	.....	*7
345	Lorain, Lorain County	Blast-furnace slag	4.8	8.2	140.3	3.6	19
570	Medina, Medina County	Gravel	.....	.....	.....	.....	4
	PENNSYLVANIA.						
339	Cedar Hollow, Chester County	Dolomite	10.6	3.8	178.1	.2	2
365	Hatboro, Montgomery County	Sandstone	10	4	166.9	.8	323
352	Northampton County	Diorite (trap)	14.3	2.8	182.2	.3	5
730	Redington, Northampton County	Dolomite	7.3	5.5	181.3	.1	*36
731	Rockhill, Huntingdon County	Diabase (trap)	34.5	1.2	193.8	.1	*30
697	Wilkesbarre, Luzerne County	Sandstone	11.6	3.4	168.8	.5	*202
	RHODE ISLAND.						
659	Providence, Providence County	Augite diorite (trap.)	20.6	1.9	187.5	.2	19
	SOUTH CAROLINA.						
488	Barnwell County	Gravel	.....	.....	.....	.....	50
374	Columbia, Richland County	Granite	13.9	2.9	163.8	.2	5
375	Pacolet, Spartanburg County	....do	20.9	1.9	166.3	.2	7

TABLE A.—*Results of laboratory tests*—Continued.

[The starred figures are the results obtained by the new method, see page 42.]

Serial No.	Locality.	Name of material.	Coefficient of wear.	Per cent of wear.	Weight in pounds per cubic foot.	Pounds of water absorbed per cubic foot.	Cementing value.
	SOUTH DAKOTA.						
449	Rowena, Minnehaha County	Quartzite	15.1	3.7	168.8	0.1	2
	TENNESSEE.						
440	Bartlett, Shelby County	Gravel	......	......	......	......	174
448	Chattanooga, Hamilton County	Limestone	14.2	2.8	168.8	.3	47
503	.....do	.....do	10.1	4	168.8	2.1	54
342	Columbia, Maury County	Chert	......	......	......	......	1,083
336	Graytown, Hickman County	Limestone	3.3	12	167.5	4.8	158
337	.....do	.....do	5.9	6.8	174.4	1.7	59
338	.....do	Chert	8.8	4.4	155.8	1.7	*240
359	.....do	Limestone	5.1	7.9	192.8	3.2	114
361	.....do	.....do	5.2	7.8	176.3	2.2	158
441	Memphis, Shelby County	Gravel	......	......	......	......	249
376	Nashville, Davidson County	Limestone	8	5	169.4	.2	231
377	.....do	.....do	7.7	5.2	168.4	.2	195
378	.....do	.....do	6.7	6	167	1.8	87
379	.....do	.....do	2.7	15.1	156.3	3.1	63
	TEXAS.						
536	Austin, Travis County	Limestone gravel	......	......	......	......	77
	VERMONT.						
726	Wallingford, Rutland County	Amphibolite	8.5	4.6	193.8	.3	*16
	VIRGINIA.						
612	Albemarle County	Chlorite schist	10.1	4	187.5	.2	8
613	.....do	Gneiss	9.8	4.1	168.8	.1	1
412	Alexandria County	Mica schist	9.3	4.3	173.8	.3	13
493	Basic City, Augusta County	Quartzite	......	......	159.4	1.3	2
537	Blacksburg, Montgomery County	Dolomite	11.2	3.6	181.3	.3	10
531	Burrowsville, Prince George County	Clay	......	......	......	......	2,531
364	Charlottesville, Albemarle County	Amphibolite	9.9	4.1	183.8	.4	36
489	.....do	Limestone	7	5.7	168.8	.2	13
490	.....do	Diorite	12.8	3.1	200	.8	5
491	.....do	Chlorite schist	5.7	7.1	184.4	.3	9
494, 495	.....do	Uralite diabase (trap).	17.3	2.3	181.3	.6	25
496	.....do	Hornblende schist	20.6	1.9	181.3	.6	9
497	.....do	.....do	9.7	4.1	187.5	1.1	7
498	.....do	Biotite schist	11.7	3.4	165.6	.3	2
533	.....do	Clay	......	......	......	......	1,661
534	.....do	.....do	......	......	......	......	475
548	.....do	Amphibolite (trap).	19.5	2.1	187.5	.6	5
549	.....do	.....do	26.7	1.5	190.6	.4	3
550	.....do	.....do	18.3	2.2	193.8	.2	6
551	.....do	.....do	24	1.7	193.8	.5	6
552	.....do	Hornblende schist	16.2	2.5	181.3	.9	10
500	Shadwell, Albemarle County	Chlorite schist	11.3	3.5	187.5	.3	14
492	Craigsville, Craig County	Limestone	9.7	4.1	168.8	.3	22
750	Fredericksburg, Spottsylvania County	.....do	7.3	5.5	175	1.5	*15
721	Jackson City, Alexandria County	Yellow clay	......	......	......	......	*500
722	.....do	Blue clay	......	......	......	......	*424
723	.....do	Yellow clay	......	......	......	......	*1,500
362	Lawrenceville, Brunswick County	Clay	......	......	......	......	3,059
499	Monticello Mountain, Albemarle County.	Quartzite	11.1	3.6	162.5	.4	4
581	Occoquan, Prince William County	Gneiss	11.7	3.4	175	.3	2
717	Manassas, Prince William County	Sandstone	......	......	......	......	*8
	WISCONSIN.						
667	Berlin, Green Lake County	Rhyolite	22.5	1.8	168.8	.05	2
668	.....do	.....do	10.1	4	168.8	.03	*1
746	Madison, Green Lake County	.....do	17	2.3	162.5	.08	*3
695	Utley, Green Lake County	.....do	8	5	162.5	.04	*5
696	.....do	.....do	7.2	5.6	162.5	.06	*5
747	.....do	Dolomite	9.8	4.1	168.8	.8	*60

TABLE A.—*Results of laboratory tests*—Continued.

[The starred figures are the results obtained by the new method, see page 42.]

Serial No.	Locality.	Name of material.	Coefficient of wear.	Per cent of wear.	Weight in pounds per cubic foot.	Pounds of water absorbed per cubic foot.	Cementing value.
	WISCONSIN—Continued.						
734	Tomah, Monroe County	Gravel					*725
735	....do	....do					*295
736	....do	....do					*197
	WASHINGTON.						
476	Seattle, King County	Quartzite	18.2	2.2	168.8	.6	47
477	....do	Basalt (trap)	19.8	2	181.3	1.9	25
508	....do	Chlorite schist	11	3.6	168.8	1	272
	DISTRICT OF COLUMBIA.						
510	Washington	Shell marl					58
511	....do	....do					741
512	....do	....do					931
	CUBA.						
472	Campo Florida	Diorite (trap)	11.7	3.4	175.0	.7	137
471	Cienfuegos	Andesite (trap)	15.2	2.6	168.8	2.2	337
473	Habana	Limestone	10.1	4	165.6	1	90
575	....do	Diorite	18.3	2.2	168.8	.8	8

TABLE B (PART I).—*Percentage of common mineral constituents*

[The small numerals placed above the percentage figures denote, respectively, whether the mineral
posed, and the secondary those resulting from subsequent change. In some cases the separate deter-
two is given in one column and an asterisk or dagger indicates the other mineral.]

	Locality.	Serial No.	Scientific name.	Common name.	Orthoclase.	Plagioclase.	Quartz.	Hornblende.
1	Charlottesville, Va	364	Amphibolite	Trap			[1]5	[1]51
2	Do	548	do	do		[1]3	[1]2	[1]87
3	Do	549	do	do			[1]4	[1]85.8
4	Do	550	do	do			[1]4	[1]82
5	Do	551	do	do		[1]1.5	[1]2.5	[1]80
6	Wallingford, Vt	726	do	do	[1]21		[1]7	[1]61.8
7	Cienfuegos, Cuba	471	Andesite	do		[1]40	[2]15	
8	Lake City, Colo	407	do	do		[1]20	[2]30	
9	Do	408	do	do		[1]55		
10	Ansonia, Conn	354	Basalt	do		[1]24.4		
11	Boundbrook, N. J	357	do	do		[1]23		
12	Do	252	do	do		[1]38		
13	Byram Station, N. J	251	do	do		[1]42		
14	Deerfield, Franklin County, Mass.	268	do	do		[1]35		
15	Guttenberg, N. J	73	do	do		[1]50		
16	Morganton, N. C	535	do	do		[1]23		
17	Seattle, Wash	477	do	do		[1]30		
18	Great Notch, N. J	260	do	do		[1]21		
19	Somerville, N. J	637	Basalt-tuff	do	[1]3			
20	Do	669	do	do	[1]3.6			
21	Wilmington, N. J	250	Basalt	do		[1]30		
22	Salisbury, Essex County, Mass.	33	Camptonite	do		[1]60		[1]25
23	Birmingham, Ala	391	Chert	Chert			[1-2]99	
24	Do	392	do	do			[1]99	
25	Do	393	do	do			[1]99	
26	Bluesprings, Nebr	360	do	do			[1]94	
27	Elco, Ill	437	do	do			[1]97.9	
28	Do	584	do	do			[1]96.5	
29	Graytown, Tenn	338	do	do	[1]0.7		[1]88.4	
30	Hot Springs, Ark	438	do	do			[1]99.8	
31	San Jose, Cal	538	do	do			[1]88.3	
32	Amherst, Hampshire County, Mass.	78	Diabase	Trap		[1]50		
33	Do	82	do	do		[1]40		
34	Brookline, Norfolk County, Mass.	7	do	do		[1]40		
35	Do	369	Diabase (altered)	do		[1]32.5	[2]4	[2]2.4
36	Do	23	Diabase	do		[1]45	[2]10	
37	Charlottesville, Va	494	Diabase (uralitic)	do		[1]32	[1]3	[2]50
38	Coweta County, Ga	415	Diabase	do		[1]42.2		
39	Deerfield, Franklin County, Mass.	76	do	do		[1]65		
40	Dickerson, Md	363	do	do		[1]33		[2]1
41	Everett, Middlesex County, Mass.	2	do	do		[1]40	[2]3	
42	Great Notch, N. J	261	do	do		[1]31		
43	Haverstraw, N. Y	49	do	do		[1]50		
44	Holyoke, Hampden County, Mass.	66	do	do		[1]50		
45	Hydepark, Norfolk County, Mass.	9	do	do		[1]35		
46	Ipswich, Essex County, Mass.	61	Diabase (uralitic)	do		[1]18		[1]66
47	Lynn, Essex County, Mass.	21	Diabase	do		[1]40		
48	Do	29	do	do		[1]40		
49	Malden, Middlesex County, Mass.	270	do	do		[1]34.2		
50	Medford, Middlesex County, Mass.	20	do	do		[1]50	[1]3	
51	Meriden, Conn	11	do	do		[1]50		
52	Do	71	do	do		[1]43		
53	Do	467	do	do		[1]25		
54	Middle Valley, N. J	405	do	do		[1]29.3	[1]2	
55	Milton, Norfolk County, Mass.	219	Diabase (uralitic)	do		[1]25		[2]*57
56	Monson, Hampden County, Mass.	68	Diabase	do		[1]55		
57	Newbury, Essex County, Mass.	31	do	do		[1]60		
58	New Providence, N. J	350	do	do		[1]20		
59	Newton, Middlesex County, Mass.	6	do	do		[1]50	[2]5	

in road-making rocks (see Part II for completed analysis).

is primary or secondary, the primary minerals being the original minerals of which the rock is com-
mination of two minerals in the same rock is impracticable, therefore the total percentage of the

Augite.	Magnetite.	Apatite.	Calcite.	Olivine.	Biotite.	Chlorite.	Serpentine.	Epidote.	Pyrite.	Muscovite.	Microcline.	Garnet.	Titanite.	
	^{1}3							^{1}41						1
					^{1}0.6			^{1}7.3						2
	^{1}0.1							^{1}10	^{1}0.1					3
	^{1}3.5							^{1}10	^{1}0.4					4
					^{1}3			^{1}6					^{1}7	5
	^{1}6		^{2}1		^{2}0.1		^{2}2		^{1}0.1			^{1}1		6
	^{1}5	^{1}1	^{2}2			^{2*}22		(^{2*})						7
	^{1}4		^{2}4.5			^{2}10		^{2}25		^{2}5.0				8
^{1}43	^{1}2													9
^{1}71.5	^{1}3.5			^{1}0.4			^{2}0.2							10
^{1}59	^{1}3						^{2}5							11
^{1}27	^{1}4					^{2}5								12
^{1}54	^{1}3				^{2}1									13
^{1}30	^{1}3.9					^{2}4			^{2}0.1					14
^{1}40	^{1}10													15
^{1}58	^{1}2			^{1}15	^{2}0.1		^{2}1.9							16
^{1}40	^{1}10						^{2}20							17
^{1}50							^{2}5							18
	^{1}2.4		^{2}17.2		^{1}0.4									19
	^{1}3		^{2}9.2		^{1}0.5									20
^{1}30	^{1}3					^{2}2								21
	$^{1-2\dagger}$5					^{2}10							($^{1-2\dagger}$)	22
	^{1}0.3					^{2}0.2								23
	^{1}0.1								^{1}0.1	^{2}0.3				24
	^{1}0.1								^{1}0.1	^{2}0.3				25
									^{1}0.1	^{1}0.9		^{1}1.2		26
	^{1}0.1													27
	^{1}0.1									^{1}0.1				28
	^{1}0.4				^{1}0.1					^{2}0.7		^{1}6.7		29
	^{1}0.1													30
			^{2}2.4											31
^{1}40	$^{1-2}$5					^{2}5								32
^{1}50	^{1}10													33
	$^{1-2}$15					^{2}40			^{1}5					34
	^{1}0.2					^{2}0.4		^{2}57.3						35
			^{2}10			^{2*}35	(^{2*})							36
	^{1}5							^{2}5	^{2}5					37
^{1}51	^{1}5.5					^{2}0.1			^{2}0.2	^{2}1				38
	$^{1-2}$10			^{1}20		^{2*}5	(^{2*})							39
^{1}55	^{1}4.8	^{1}0.1	^{2}1		^{1}0.1	^{2}1				^{2}4				40
	$^{1-2}$10	^{1}2		^{1}15	^{1}20	^{2*}10	(^{2*})							41
^{1}37	^{1}5						^{2}5							42
^{1}40	$^{1\ 2}$5						^{2}5							43
^{1}40	^{1*}10								(^{1*})					44
^{1}30	^{1}10	^{1}3			^{1}12	^{2†}10		(^{2†})						45
	^{1}5							^{2}11						46
^{1}40	$^{1-2}$8					^{2†}12			(^{2†})					47
^{1}30	$^{1-2}$10					^{2}20								48
^{1}19	^{1}7		^{2}2.3			^{2}9		^{2}0.5						49
	^{2}10			^{1}5		^{2†}30	(^{2†})	(^{2†})	^{2}2					50
^{1}10	$^{1-2}$10		^{2}5			^{2†}25	(^{2†})							51
^{1}17	^{1}7		^{2}10			^{2}11								52
^{1}40	^{1}4		^{2}5			^{2}10				^{2}10				53
^{1}30	^{1}8	^{1}0.5			^{1}1	^{2}9			^{1}0.2					54
	^{1}5				^{2}13	(^{2*})								55
^{1}40	^{1*}5								(^{1*})					56
^{1*}35	$^{1-2}$2			(^{1*})		^{2}3								57
^{1}30	^{1}4					^{2}5								58
	$^{1-2}$10					^{2}25		^{2}10						59

TABLE B (PART I).—*Percentage of common mineral constituents in*

	Locality.	Serial No.	Scientific name.	Common name.	Orthoclase.	Plagioclase.	Quartz.	Hornblende.
60	Quincy, Norfolk County, Mass.	18	Diabase	Trap	......	[1]*50	......	......
61	Do	299	Diabase (uralitic)	do	......	......	([2]†)	[2]†79.4
62	Roberts Station, Ga	420	Diabase	do	......	[1]58.3	......	......
63	Rockhill, Pa	731	do	do	......	[1]63.6	......	......
64	Rockland Lake, N. Y	335	do	do	[1]1	[1]40	[1]1	[2]5
65	Saugus, Essex County, Mass	22	do	do	......	[1]45	......	......
66	Do	25	do	do	......	[1]40	......	......
67	Do	28	do	do	......	[1]40	......	......
68	Do	32	do	do	......	[1]50	......	......
69	Do	84	do	do	......	[1]50	......	......
70	Shadyside, N. J	566	do	do	......	[1]49	......	[2]11
71	Somerville, Middlesex County, Mass.	19	Diabase (gabbroitic).	do	......	[1]56.4	......	......
72	Do	75	Diabase	do	......	[1]45	......	......
73	Sterling, Worcester County, Mass.	83	do	do	......	[1]55.3	......	......
74	Ware, Hampshire County, Mass.	64	do	do	......	[1]35	......	......
75	Westfield, Hampden County, Mass.	517	do	do	......	[1]48	......	......
76	West Springfield, Hampden County, Mass.	12	do	do	......	[1]45	......	......
77	Do	67	do	do	......	[1]40	......	......
78	Do	91	do	do	......	[1]50	......	......
79	Do	93	do	do	......	[1]50	......	......
80	Winchester, Middlesex County, Mass.	59	do	do	......	[1]30	......	......
81	Asheville, N. C	628	Diorite	do	[1]25	[1]6	[1]24.9	[1]35
82	Beverly, Essex County, Mass.	117	do	do	[1]27	[1]6	[1]5	[1]33
83	Campo, Fla	472	do	do	......	[1]60	[1]15	[1]15
84	Charlottesville, Va	490	do	do	......	[1]22	......	[1]72
85	Delaware River, Pa	352	do	do	......	[1]44.8	[1]9	[1]16
86	Havana, Cuba	575	do	do	......	[1]4	[1]5	[1]27
87	Lake City, Colo	409	do	do	......	[1]67.5	[1]7	......
88	Millville, Worcester County, Mass.	227	do	do	[1]10	[1]31.3	[1]9	[1]30
89	Newbury, Essex County, Mass.	35	do	do	[1]*40	([1]*)	[1]10	[1]40
90	Providence, R. I	659	Augite-diorite	do	......	[1]33	......	[1]37.2
91	Salem, Essex County, Mass.	1	do	do	[1]*50	([1]*)	......	[1]20
92	Do	611	Diorite (vogesite).	do	[1]63	[1]3	......	[1]1
93	Watertown, Middlesex County, Mass.	96	Diorite	do	......	[1]55	[2]2	[1]15
94	Winchester, Middlesex County, Mass.	56	do	do	......	[1]40	[2]2	[1]45
95	Do	304	do	do	......	[1]46	......	[1]34
96	Canton, Ga	583	Eclogite	Garnet rock	......	......	[1]21	[1]3.3
97	Glen Mills, Pa	254	do	do	......	[1]40	......	[1]1
98	Ashboro, N. C	514	Felsite	Porphyry	[1]*81.7	......	([1]*)	......
99	Boston, Suffolk County, Mass.	40	do	do	[1]*90	([1]*)	[1]8	......
100	Lynn, Essex County, Mass.	24	do	do	[1]*95	......	([1]*)	......
101	Do	27	do	do	[1]*85	([1]*)	[1]5	......
102	Quincy, Norfolk County, Mass.	72	do	do	[1]*80	......	[1]5	......
103	Revere, Suffolk County, Mass.	3	do	do	[1]95	......	[1]2	......
104	Do	124	do	do	[1]*97.4	......	([1]*)	......
105	Rowley, Essex County, Mass.	97	do	do	[1]*95	......	([1]*)	......
106	Saugus, Essex County, Mass.	86	do	do	[1]*90	......	([1]*)	......
107	Do	87	do	do	[1]*95	([1]*)	[1]†5	......
108	Weymouth, Norfolk County, Mass.	92	do	do	[1]*90	......	([1]*)	......
109	Bergen, N. J	249	Gabbro	Trap	......	[1]44	......	[2]0.5
110	Cortland, N. Y	195	do	do	......	[1]48	......	......
111	Lambertsville, N. J	253	Uralite-gabbro	do	......	[1]23	[1]3	[2]26
112	Do	387	Gabbro	do	......	[1]35	......	[2]17
113	Rocky Hill, N. J	248	do	do	......	[1]68	......	......
114	Do	285	Uralite-gabbro	do	......	[1]9	[1]8	[1-2]27
115	Athol, Worcester County, Mass.	88	Gneiss	Gneiss	[1]8	[1]0.2	[1]80.8	......
116	Albemarle County, Va	613	do	do	[1]26.4	[1]7	[1]45	......
117	Atlanta, Ga	422	Hornblende-gneiss	do	......	[1]4.2	[1]23.5	[1]70
118	Auburn, Worcester County, Mass.	203	Gneiss	do	[1]51.4	[1]3	[1]30	......

road-making rocks (see Part II for completed analysis)—Continued.

Augite.	Magnetite.	Apatite.	Calcite.	Olivine.	Biotite.	Chlorite.	Serpentine.	Epidote.	Pyrite.	Muscovite.	Microcline.	Garnet.	Titanite.	
......	[2]5	......	[2]10	......	......	[2]30	......	[2]5	......	([1]*)	......	......	......	60
[1]9	[1]7	......	......	......	[2]0.1	[2]4.5	......	([2]†)	......	......	......	......	......	61
[1]30	[1]6.2	......	......	......	......	[2]1.1	......	......	......	......	......	......	......	62
[1]35	[1].2	......	......	......	[1]0.8	[2]0.4	......	......	......	......	......	......	......	63
[1]35	[1]9.9	[1]0.1	......	......	......	[2]1	......	......	......	......	......	......	......	64
[1]35	[1-2]10	......	......	......	......	[2*]10	([2*])	......	......	......	......	......	......	65
[1]30	[1-2]10	......	......	......	[1]2	[2*]10	([2*])	[2]5	......	......	......	......	[1]3	66
[1]20	[1-2]15	[1*]2	......	......	......	......	[2†]23	([2]†)	......	......	......	......	([1]*)	67
[1]25	[1-2]8	......	......	......	......	[2*]15	......	([2]*)	......	......	......	......	[1]2	68
......	[1]5	......	......	[1]20	......	[2*]20	([2]*)	[2]5	......	......	......	......	......	69
[1]22	[1]2.5	......	......	......	[1]0.5	......	......	......	......	[2]9	......	......	......	70
[1]12	[1]2	[1]0.5	[2]3	......	[1]2	[2]10	......	[2]0.1	......	......	......	......	......	71
......	[1]10	......	......	[1*]25	[1]15	......	([2]*)	......	......	......	......	......	......	72
[1]41	[1]3	......	[2]0.2	......	[1]0.3	......	[2]0.1	......	......	......	......	......	......	73
[1]60	[1]5	......	......	......	......	......	......	......	......	......	......	......	......	74
[1]39	[1]3	......	......	[1]4	......	[2]1	[2]2	......	......	......	......	......	......	75
[1]50	[1-2*]5	......	......	......	......	([2]*)	......	......	......	......	......	......	......	76
[1]50	[1*]10	......	......	......	......	......	......	......	([1]*)	......	......	......	......	77
[1]30	[1]5	......	......	......	......	[2]15	......	......	......	......	......	......	......	78
[1]30	[1]10	......	......	......	......	[2]10	......	......	......	......	......	......	......	79
[1]50	......	......	......	......	......	[2]15	......	......	[1-2]5	......	......	......	......	80
......	......	[1]1	......	......	......	......	......	......	[1]4	......	......	[1]2	[1]1	81
[1]1	[1]2	[1]1	[2]1	......	[1]8	......	......	......	......	......	......	......	......	82
......	[1*]1	([1]*)	......	......	......	[2]2	......	......	[2]5	......	......	......	......	83
......	[1]2	......	......	......	......	......	......	......	......	......	......	......	[2]4	84
......	[1]5	......	......	......	[1]7	......	......	[2]8	......	......	......	......	......	85
......	[1]0.2	......	[2]4	......	......	[2]2	......	......	......	......	......	......	......	86
......	[1]6	[1]0.1	[2]4	......	[1]13	[2]2	......	[2]0.2	......	......	......	......	[1]0.1	87
......	[1]5	[1]0.1	[2]2	......	[1]6	......	......	[2]4	[1]1	......	......	......	......	88
......	[1]2	[1]1	[2*]4	......	......	([2]*)	......	......	......	......	......	......	[1]3	89
[1]5	[1]6	[1]0.5	[2]0.1	......	[1]7	......	......	[2]0.1	[1]0.1	......	......	......	......	90
[1]16	[1]10	[1†]4	([2]†)	......	......	......	......	......	......	......	......	......	......	91
[1]15.8	[1]8	[1]1	......	......	......	[2]7.2	......	......	......	......	......	......	......	92
......	[1*]5	......	[2]3	......	[1]10	[2†]10	......	([2]†)	([1]*)	......	......	......	......	93
......	[1*]10	[1]3	......	......	......	......	......	......	([1]*)	......	......	......	......	94
......	[1]2	[1]0.3	......	......	[1]2.5	......	......	[2]0.1	[2]0.1	......	......	......	......	95
......	[1]1.3	......	[2]1	......	......	[2]3	......	......	......	......	......	[1]70.4	......	96
[1]27	[1]6	......	[2]1	......	......	......	......	......	......	......	......	[1]25	......	97
......	[1]0.1	[1]0.1	......	......	[1]10	[2†]8.1	......	([2]†)	......	......	......	......	......	98
......	......	......	......	......	......	......	......	......	[1]2	......	......	......	......	99
......	[1]5	......	......	......	......	......	......	......	......	......	......	......	......	100
......	......	......	......	......	......	......	......	......	......	......	......	......	......	101
......	[1]5	......	......	......	......	[2]10	......	......	......	([2]*)	......	......	......	102
......	......	......	......	......	......	[2]3	......	......	......	......	......	......	......	103
......	[1]0.1	......	[2]0.1	......	......	[2]0.2	......	[2]0.1	......	......	......	......	......	104
......	[1]5	......	......	......	......	......	......	......	......	......	......	......	......	105
......	[1-2†]10	......	......	......	......	([2]†)	......	([2]†)	......	......	......	......	......	106
......	......	......	......	......	([2]†)	......	......	......	......	......	......	......	......	107
......	[1†]10	......	......	......	......	([2]†)	......	......	......	......	......	......	......	108
[1]42.5	[1]2	[1]1	......	......	[1]2	[2]1	......	......	......	......	......	......	......	109
[1]13	[1]2	[1]1	......	......	[1]22	......	......	......	......	......	......	......	......	110
[1]15	[1]2	......	......	......	[1]1	......	......	......	......	......	......	......	......	111
[1]28	[1]1	......	......	......	[1]0.7	[2]0.1	......	......	......	......	......	......	......	112
[1]24	[1]2	......	......	......	[1]2	[2]1	......	......	......	......	......	......	......	113
[1]8	[1]1	[1]0.1	[2]0.1	......	[1]1	......	......	[2]10	......	......	......	......	......	114
......	[1]0.4	[1]0.1	......	......	[1]10	......	......	......	[2]0.1	......	......	......	[1]0.2	115
......	[1]0.1	......	......	......	[1]1.4	......	......	......	......	[1-2]19	......	......	......	116
......	......	[1]0.3	......	......	......	......	......	......	[1]2	......	......	......	......	117
......	[1]0.5	......	......	......	[1]4	......	......	......	......	[1]10	[1]0.5	[1]0.4	......	118

TABLE B (PART I).—*Percentage of common mineral constituents in*

	Locality.	Serial No.	Scientific name.	Common name.	Orthoclase.	Plagioclase.	Quartz.	Hornblende.
119	Augusta, Ga	419	Granite-gneiss	Gneiss	[1]27	....	[1]60.8	....
120	Ashby, Middlesex County, Mass.	118	Gneiss	....do	[1]49	[1]7	[1]27	....
121	Dartmouth, Bristol County, Mass.	77	.....do	....do	[1*]55 *a*	....	[1]30	....
122	Duxbury, Plymouth County, Mass.	5	.....do	....do	[1*]40	([1*])	[1–2]50	....
123	Lee, Berkshire County, Mass.	51	Hornblende gneiss	....do	[1]14	[1]2	[1]50	[1]14
124	Little Falls, N. Y	532	Granite gneiss	....do	[1]40	....	[1]49	[1]9
125	Marion, Plymouth County, Mass.	13	Gneiss	....do	[1]30	....	[1–2]30	....
126	Newburyport, Essex County, Mass.	37	.....do	....do	[1*]40	([1*])	[1]40	....
127	Occoquan, Va	581	.....do	....do	[1]18	[1].1	[1]53.4	....
128	Round Island, N. Y	100	.....do	....do	[1]15	....	[1]15	[1]10
129	Toccoa, Ga	468	Granite gneiss	....do	....	....	[1]50	....
130	Uxbridge, Worcester County, Mass.	63	Gneiss	....do	[1]30	[1]20	[1]10	[1]35
131	Westport, Bristol County, Mass.	81	.....do	....do	[1]45	....	[1*]40	....
132	Ashby, Middlesex County, Mass.	60	Granite	Granite	[1]25	[1]7	[1]56.9	....
133	Asheville, N. C	627	.....do	....do	[1]55	....	[1]25	....
134	Beverly, Essex County, Mass.	62	Hornblende granite	....do	[1]50	[1]10	[1]20	[1]8
135	Do	74	Granite	....do	[1]40	....	[1]20	....
136	Do	89	Hornblende granite	....do	[1]40	[1]10	[1]30	[1]10
137	Clinton, Worcester County, Mass.	242	Gneissoid granite	....do	[1]8	....	[1]66	....
138	Do	279	Granite	....do	[1]12	[1].3	[1]66.6	....
139	Columbia, S. C	374	.....do	....do	[1]43.4	[1]1	[1]31	[1].4
140	Concord, N. C	434	.....do	....do	[1]8	[1]5	[1]70	....
141	Do	436	.....do	....do	[1]25	....	[1]5	....
142	Elberton, Ga	416	.....do	....do	[1]77.3	[1]3	[1]9	....
143	Elm City, N. C	431	.....do	....do	[1]36.5	[1]10	[1]30	....
144	Fitchburg, Worcester County, Mass.	256	.....do	....do	[1]52.5	[1]2	[1]30	....
145	Gloucester, Essex County, Mass.	26	Hornblende granitite	....do	[1]53.8	[1]2	[1]15	[1]11
146	Hanover, N. H	370	Gneissoid granite	....do	[1]29.7	[1].2	[1]30	....
147	Lithonia, Ga	421	Granite	....do	[1]32	[1]6	[1]41.7	....
148	Los Angeles, Cal	578	.....do	....do	[1]53	[1]8.6	[1]32	....
149	Northampton, Hampshire County, Mass.	8	Hornblende granitite	....do	[1]33.2	[1]2	[1]22	[1]11
150	Orange, Franklin County, Mass.	39	.....do	....do	[1]15	[1]33	[1]40.6	[1].4
151	Pacolet, S. C	375	Granite	....do	[1]48	....	[1]36.6	....
152	Quincy, Norfolk County, Mass.	17	.....do	....do	[1†]75 *a*	....	[1]20	[1*]5
153	Rockport, Essex County, Mass.	34	.....do	....do	[1*]75	([1*])	[1]23	....
154	Saugus, Essex County, Mass.	15	.....do	....do	[1*]30	([1*])	[1]55	....
155	Do	32	.....do	....do	[1]35	[1]10	[1]50	[1]5
156	Sherman, Colo	397	.....do	....do	[1]15	[1]9	[1]21	....
157	Taunton, Bristol County Mass.	445	.....do	....do	[1]15	[1]3	[1]55	....
158	Waltham, Middlesex County, Mass.	4	.....do	....do	[1]50	[1]35	[1]10	....
159	Wilson, N. C	432	Granitite	....do	[1]49.3	[1]10	[1]15	....
160	Do	433	Granite	....do	[1]50	[1]32	[1]5	....
161	Winchester, Middlesex County, Mass.	57	.....do	....do	[1]60	....	[1]20	[1]10
162	Do	58	.....do	....do	[1]30	[1]40	[1]7	....
163	Worcester, Worcester County, Mass.	266	.....do	....do	[1]30.8	[1]10	[1]37	....
164	Cumberland, R. I	14	Peridotite	Trap	[1*]50	([1*])	....	....
165	Wanaque, N. J	478	Peridotite (Lherzolite)	....do	....	....	....	....
166	Basic City Va	493	Quartzite	Quartzite	[1*]4.8	([1*])	[1]94	....
167	East Providence, R. I	43	.....do	....do	[1]7	[1]3	[1]41	....
168	Do	48	.....do	....do	[1]5	[1]2	[1]47	....
169	Great Barrington, Berkshire County, Mass.	80	.....do	....do	[1]7	....	[1]76.4	....
170	Lee, Berkshire County, Mass.	121	.....do	....do	....	....	[1]98.1	....
171	Merrimac, Essex County, Mass.	329	.....do	....do	....	....	[1]71.5	....

[a] See pages 70 and 71, Part II, for the mineral indicated by asterisk or dagger.

road-making rocks (see Part II for completed analysis)—Continued.

Augite.	Magnetite.	Apatite.	Calcite.	Olivine.	Biotite.	Chlorite.	Serpentine.	Epidote.	Pyrite.	Muscovite.	Microcline.	Garnet.	Titanite.	
......	[1]5	[1]0.1	[2]3	......	......	[2]2	......	......	......	......	......	......	......	119
......	......	[1]0.1	......	......	[1]3.9	......	......	[2]0.2	......	[1]1.3	[1]9	......	......	120
......	[1]2	[1]1	......	......	......	......	......	......	[1]3	[1]5	......	[1]3	......	121
......	......	......	......	......	......	[2]10	......	......	......	......	......	......	......	122
......	[1]2	......	......	......	[1]11	......	......	[2]5	......	......	......	[1]2	......	123
......	[1]1.2	[1].7	......	......	[1].1	......	......	......	......	......	......	......	......	124
......	......	......	......	......	[1]10	......	......	[2]4	......	......	[1]25	......	[1]1	125
......	......	......	......	......	......	[2]12	......	[2]7	[2]1	......	......	......	......	126
......	......	......	......	......	[1]8.7	......	......	[2]14	[1].1	[1]5.4	......	[1].1	[1].1	127
......	[1]4	[1]*1[a]	......	......	......	......	......	......	......	......	[1]20	......	......	128
......	[1]2	[1]1	......	......	[1]4	......	......	[2].1	[1]1	[1]6	[1]34.5	[1]1.3	......	129
......	......	[1]*5[a]	......	......	......	......	......	......	......	......	......	......	......	130
......	......	......	......	......	[1]10	......	......	......	......	[1]†5	([1]*)	([1]†)[a]	......	131
......	......	[1].1	......	......	[1]8	......	......	......	......	[1]2	......	......	......	132
......	......	......	......	......	[1]5	......	......	......	......	[1]13	......	......	......	133
......	......	[1]*2[a]	......	......	[1]10	......	......	......	......	......	......	......	......	134
[1]20	[1]*5	......	......	......	[1]10	......	......	......	([1]*)	......	......	......	[1]5	135
......	[1]*5	([1]*)	......	......	[1]5	......	......	......	......	......	......	......	......	136
......	[1]1	......	[2]2	......	[1]7	......	......	[2]2	......	[1]7	[1]6	[1]1	......	137
......	[1]1	......	......	......	[1]6	[2]*2	......	([2]*)	......	[1]10	......	......	......	138
......	[1].1	[1].1	......	......	[1]17	......	......	......	......	......	......	......	......	139
......	[1].1	[1]1	......	......	......	......	......	......	......	[1]7	[1]5	......	......	140
[1]5	[1]4	[1].5	......	......	......	......	......	......	......	......	[1]60	......	......	141
......	[1].1	[1].1	......	......	[1]5	......	......	......	......	[1]1	[1]3	......	......	142
......	[1].1	......	......	......	[1]2	[2]1.4	......	[2]2	......	[2]1.5	[1]15	......	......	143
......	[1].4	[1].1	......	......	[1]10	......	......	......	......	[1]3	......	......	......	144
......	[1].1	......	......	......	[1]8	[2].1	......	......	......	......	......	......	......	145
......	......	......	......	......	[1]7	[2].1	......	[2]3	......	[1]5	[1]15	......	......	146
......	[1]2	[1].1	......	......	[1]1	......	......	......	......	[1]2	[1]15	......	[1].2	147
......	[1].5	......	......	......	[1].5	......	......	......	......	......	[1]2	......	......	148
[1]1.7	......	[1].1	[2]4	......	[1]3	[2]6	......	[2]2.4	[2].1	......	......	......	[1].5	149
[1].5	[1].1	[1].2	......	......	[1]10	[2].1	......	......	......	......	......	......	......	150
......	[1]1	[1].4	......	......	[1]7	......	......	......	......	[1]7	......	......	......	151
......	......	([1]*)	......	......	......	......	......	......	......	......	......	......	......	152
......	......	......	......	......	......	......	......	......	......	......	......	......	......	153
......	......	......	[2]3	......	......	[2]10	......	......	......	......	......	......	[1]2	154
......	......	......	......	......	......	......	......	......	......	......	......	......	......	155
......	[1].2	[1].1	[2]1	......	[1]1	[2]8	......	......	......	[1]2.2	[1]41.5	......	......	156
......	......	......	......	......	......	[2]1	......	[2]5	......	[2]20	......	......	......	157
......	......	......	......	......	......	[2]5	......	......	......	......	......	......	......	158
......	[1].5	......	......	......	[1]6	[2].2	......	......	......	......	[1]4	......	......	159
......	[1].3	......	[2]2	......	......	[2]1	......	......	......	[1].7	......	......	......	160
......	[1]*6	......	......	......	......	......	......	[2]4	......	......	......	......	([1]*)	161
......	[1]2	......	......	......	[1]10	......	......	......	......	......	[1]10	......	[1]*1[a]	162
......	[1]1	......	......	......	[1]3	......	......	......	......	[1]5	[1]4	[1]2	[2]0.2	163
......	[1-2]15	......	......	......	......	[2]35	......	......	......	......	......	......	......	164
[1]32	[1]10	......	......	[1]10	......	......	[2]8	......	......	......	......	......	......	165
......	......	......	......	......	......	......	......	......	......	......	......	......	......	166
......	[1]1	......	......	......	[1]2	[2]7	......	[2]8	......	[1]30	......	......	......	167
......	[1]1	......	......	......	[1]1	[1]6	......	[2]6	......	[1]32	......	......	......	168
......	......	[1].2	......	......	[1]4	......	......	[2]2	......	[1]10	[1]0.3	......	......	169
......	[1]1	[1].2	......	......	......	......	......	......	......	......	......	......	......	170
[1].3	......	......	[2]9	......	[1]3	[2]4	......	......	......	[1]12	......	......	......	171

[a] See pages 70 and 71, Part II, for the mineral indicated by asterisk or dagger.

TABLE B (PART I).—*Percentage of common mineral constituents in*

	Locality.	Serial No.	Scientific name.	Common name.	Orthoclase.	Plagioclase.	Quartz.	Hornblende.
172	Methuen, Essex County, Mass.	181	Quartzite	Quartzite			[1]81	
173	Do	226	do	do			[1]66.4	[1]14
174	Monticello, Va.	499	do	do	[1]35		[1]57	
175	Newport, R. I.	189	do	do			[1]98.1	
176	Rowena, S. Dak.	449	do	do	[1]2		[1]94	
177	Seattle, Wash	476	do	do	[1]10		[1]61	
178	Berlin, Wis.	667	Rhyolite	Porphyry.	[1*]88.3	[1]2	([1*])	
179	Do	668	do	do	[1*]88		([1*])	
180	Brookline, Norfolk County, Mass.	368	do	do	[1]10		[1-2]25	[2]5
181	Capital City, Colo.	399	Rhyolite (breccia)	do	[1*]77.4	[1]1	([1*])	
182	Hinsdale, Colo.	398	Rhyolite	do	[1*]70.9		([1*])	
183	Lake City, Colo.	396	Rhyolite (breccia)	do	[1]70		[1-2]20.5	
184	Lake Shore, Colo.	406	Rhyolite (tuff)	do	[1]15		[1]36.7	
185	Madison, Wis	746	Rhyolite	do	[1]56		[1]38.5	[1]5.5
186	Utley, Wis	695	do	do	[1*]91		([1*])	
187	Do	696	do	do	[1*]93		([1*])	
188	Cumberland, Md.	427	Sandstone	Sandstone			[1]86.8	
189	Wilkesbarre, Pa.	697	do	do			[1]86	
190	Deerpark, N. Y.	344	do	do	[1*]82.9		([1*])	
191	Duanesburg, N. Y.	94	do	do	[1]4	[1]1	[1]55	
192	Fort Smith, Ark.	742	do	do	[1]4		[1]91	
193	Do	743	do	do	[1]4		[1]82.8	
194	Kentawa, Ky	457	do	do			[1]95.5	
195	Milton, Norfolk County, Mass.	196	do	do	[1]7	[1]1	[1]83	
196	Stonington, Miss.	453	do	do	[1]5		[1]93	
197	Vicksburg, Miss.	763	do	do	[1]5	[1].5	[1]22	
198	Albemarle County, Va.	612	Chlorite schist	Schist			[1]31.7	
199	Alexandria County, Va.	412	Mica schist	do	[1]8	[1]1	[1]63.4	
200	Asheville, N. C.	469	Hornblende schist	do				[1]95.9
201	Do	705	do	do			[1]8	[1]79.5
202	Athol, Mass	88	Schist	do			[1]80	
203	Buckland, Franklin County, Mass.	52	Augite mica schist	do	[1*]74.8	[1]1	([1*])	
204	Charlottesville, Va	491	Chlorite schist	do			[1]17	
205	Do	496	Hornblende schist	do		[1]14	[1]10	[1]65
206	Do	497	do	do		[1]25		[1]58
207	Do	498	Biotite schist	do	[1]15	[1]2	[1]38	
208	Do	552	Hornblende schist	do		[1]6	[1]30	[1]46
209	Chester, Hampden County, Mass.	44	do	do			[1]21	[1]76.8
210	Clinton, Worcester County, Mass.	244	Mica schist	do	[1]9		[1]21	
211	Goat Island, Wash.	508	Chlorite schist	do	[1*]5	([1*])	[1]25	
212	Great Barrington, Berkshire County, Mass.	98	Mica schist	do			[1]65	
213	Hanover, N. H.	371	Hornblende schist	do		[1]15	[1]13.4	[1]60
214	Lebanon, N. H.	372	do	do		[1]12	[1]10	[1]73
215	Do	373	Biotite schist	do	[1]6	[1]4	[1]51.8	
216	Lenox, Berkshire County, Mass.	10	Muscovite schist	do			[1]25	
217	Pittsfield, Berkshire County, Mass.	69	Mica schist	do			[1]30	
218	Quincy, Norfolk County, Mass.	718	Chlorite schist	do			[1-2]32.7	
219	Rockport, Me	123	Biotite schist	do			[1]38	
220	Shadwell, Va	500	Chlorite schist	do		[1]24	[1]1	
221	Webster, Worcester County, Mass.	411	Muscovite schist	do			[1]20	
222	Brookline, Norfolk County, Mass.	367	Slate	Slate			[1]9	
223	Hudson, N. Y.	385	do	do			[1]72	
224	Concord, N. C.	513	Syenite	Trap	[1]85.4			[1]0.4
225	Gloucester, Essex County, Mass.	30	Augite syenite	do	[1]81.5		[1]4	[1]5
226	Milton, Norfolk County, Mass.	218	do	do	[1*]62.7	([1*])	[1]13	
227	Salem, Essex County, Mass.	115	do	do	[1]58.5	[1]2.5		
228	Waltham, Middlesex County, Mass.	639	Syenite	do	[1]50.4	[1]18	[1]7	
229	California	79	Trachyte	do	[1*]95	([1*])	[1]5	
230	Saugus, Essex County, Mass.	90	do	do	[1*]80	([1*])		

road-making rocks (*see Part II for completed analysis*)—Continued.

Augite.	Magnetite.	Apatite.	Calcite.	Olivine.	Biotite.	Chlorite.	Serpentine.	Epidote.	Pyrite.	Muscovite.	Microcline.	Garnet.	Titanite.	
			[2]10			[2]6								172
	[1].2		[2]1		[1]16			[2]2.4						173
			[2]3.5											174
	[1]1	[1].2								[1].1				175
	[1].1							[2]1.1			[1].1			176
			[2]9.8		[1]2	[2].5					[1]3			177
			[2].1		[1]5.1					[2]3.2				178
	[1]1				[1]9									179
	[1]2		[2]2			[2]16		[2]40						180
	[1]1		[2]6							[1]7.6	[1]2			181
	[1]2.4	[1].1	[2]3			[2]3				[1]15.6				182
	[1].5		[2]5		[1]1									183
	[1]6.5		[2]12.4						[2]3.4					184
														185
	[1]2.9		[2]1		[1-2]5									186
	[1]2		[2]1		[1] [2]3.8									187
										[1]2				188
	[1]2	[1].1	[2]5			[2]4			[1].1	[2]1.4				189
	[1].4				[1]3.5	[2]1.4		[2].4		[1]7				190
	[1]1		[2]4			[2]3								191
	[1].1									[1].3				192
	[1].1									[1]2				193
														194
			[2]1			[2]1				[1]1				195
	[1].4									[1].1				196
	[1].2													197
			[2]3			[2]22		[2]42					[1]3	198
		[1].1			[1]7	[2]1			[2]1	[1]18		[1].4		199
	[1]1					[2].1			[1]3					200
	[1].4											[1]10	[2]2	201
					[1]15									202
[1]8		[1].1			[1]12					[1]3	[1]1	[1].1		203
					[1].5	[2]47		[2]34.5						204
	[1]3							[2]8						205
	[1]2							[2]12					[2]3	206
	[1]4	[1]1			[1]8.9			[2]10		[1]21				207
	[1]4.5					[2]1		[2]12						208
	[1]2							[2].1						209
					[1]12			[2]29.9		[1]28				210
			[2]2			[2]30			[2].2	[1]36.8				211
		[1]3			[1]20			[2]5		[1]7				212
	[1]3		[2]3.6					[2]5						213
	[1]5													214
	[1]2				[1]32	[2].2						[1]4		215
	[1]5				[1]3	[2]*5		([2]*)		[1]60		[1]2		216
	[1]*5		[2]20		[1]20				([1]*)	[1]25				217
	[1]6		[2]6		[1].1	[2]40		[2]15	[1].1				[1].1	218
	[1]2				[1]53			[2]5	[1]1			[1]1		219
	[1]3					[2]45		[2]27						220
					[1]14	[2]7			[2].2	[1]58.6				221
	[1]4.5		[2]3					[2]20.2		[1]63.3				222
	[1].9		[2]3						[1].1	[1]24				223
[1]3	[1]2.5	[1].1			[1]1					[1].1	[1]2.5			224
[1]4	[1]1				[1]3				[1].5					225
[1]20	[1]2		[2].1		[1]1				[2].1				[1].1	226
[1]22.8	[1]5	[1].1	[2]5			[2]3		[2]2	[1].1					227
			[2]5			[2]4		[2]12		[1]25				228
														229
	[1-2]5		[2]5			[2]10								230

TABLE B (PART II).—*Percentage of rarer*

[The small numerals placed above the percentage figures denote, respectively, whether the mineral posed, and the secondary those resulting from subsequent change. In some cases the separate determ two is given in one column and an asterisk or dagger indicates the other mineral.]

	Locality.	Serial No.	Scientific name.	Common name.	Fluorite.	Microperthite.	Hematite.	Zircon.
1	Charlottesville, Va	364	Amphibolite	Trap				
2	Do	548	do	do				
3	Do	549	do	do				
4	Do	550	do	do				
5	Do	551	do	do				
6	Wallingford, Vt	726	do	do				
7	Cienfuegos, Cuba	471	Andesite	do				
8	Lake City, Colo	407	do	do				
9	Do	408	do	do				
10	Ansonia, Conn	354	Basalt	do				
11	Boundbrook, N. J	357	do	do				
12	Do	252	do	do				
13	Byram Station, N. J	251	do	do				
14	Deerfield, Franklin County, Mass.	268	do	do				
15	Guttenberg, N. J	73	do	do				
16	Morganton, N. C	535	do	do				
17	Seattle, Wash	477	do	do				
18	Great Notch, N. J	260	do	do				
19	Somerville, N. J	687	Basalt tuff	do			^{2}5.0	
20	Do	669	do	do				
21	Wilmington, N. J	250	Basalt	do				
22	Salisbury, Essex County, Mass.	33	Camptonite	do				
23	Birmingham, Ala	391	Chert	Chert				
24	Do	392	do	do				
25	Do	393	do	do				
26	Bluesprings, Nebr	360	do	do				
27	Elco, Ill	437	do	do				
28	Do	584	do	do				
29	Graytown, Tenn	338	do	do				
30	Hot Springs, Ark	438	do	do				
31	San Jose, Cal	538	do	do			^{2}2.5	
32	Amherst, Hampshire County, Mass.	78	Diabase	Trap				
33	Do	82	do	do				
34	Brookline, Norfolk County, Mass.	7	do	do				
35	Do	369	Diabase (altered)	do			^{2}3.2	
36	Do	23	Diabase	do				
37	Charlottesville, Va	494	Diabase (uralitic)	do				
38	Coweta County, Ga	415	Diabase	do				
39	Deerfield, Franklin County, Mass.	76	do	do				
40	Dickerson, Md	363	do	do				
41	Everett, Middlesex County, Mass.	2	do	do				
42	Great Notch, N. J	261	do	do				
43	Haverstraw, N. Y	49	do	do				
44	Holyoke, Hampden County, Mass.	66	do	do				
45	Hydepark, Norfolk County, Mass.	9	do	do				
46	Ipswich, Essex County, Mass.	61	Diabase (uralitic)	do				
47	Lynn, Essex County, Mass.	21	Diabase	do				
48	Do	29	do	do				
49	Malden, Middlesex County, Mass.	270	do	do				
50	Medford, Middlesex County, Mass.	20	do	do				
51	Meriden, Conn	11	do	do				
52	Do	71	do	do				
53	Do	467	do	do				
54	Middle Valley, N. J	405	do	do				
55	Milton, Norfolk County, Mass.	219	Diabase (uralitic)	do				
56	Monson, Hampden County, Mass.	68	Diabase	do				
57	Newbury, Essex County, Mass.	31	do	do				
58	New Providence, N. J	350	do	do				
59	Newton, Middlesex County, Mass.	6	do	do				

mineral constituents in road-making rocks.

is primary or secondary, the primary minerals being the original minerals of which the rock is com-
mination of two minerals in the same rock is impracticable, therefore the total percentage of the

Allanite.	Rutile.	Limonite.	Glaucophane.	Rock glass.	Tourmaline.	Kaolin.	Scolecite.	Natrolite.	Hypersthene.	Nephelite.	Opal.	
...	...	...	...	...	...	...	...	...	...	...	...	1
...	...	[2]0.1	...	...	...	...	...	...	...	...	...	2
...	...	...	...	...	...	...	...	...	...	...	...	3
...	...	[2]0.1	...	...	...	...	...	...	...	...	...	4
...	...	...	...	...	...	...	...	...	...	...	...	5
...	...	...	...	...	...	...	...	...	...	...	...	6
...	...	...	...	[1]15.0	...	...	...	...	...	...	...	7
...	...	[2]1.5	...	...	...	...	...	...	...	...	...	8
...	...	...	...	...	...	...	...	...	...	...	...	9
...	...	...	...	...	...	...	...	...	...	...	...	10
...	...	...	...	[1]10	...	...	...	...	...	...	...	11
...	...	...	...	[1]7	...	[2]19	...	...	...	...	...	12
...	...	...	...	...	...	...	...	...	...	...	...	13
...	...	...	...	[1]12	...	[2]15	...	...	...	...	...	14
...	...	...	...	...	...	...	...	...	...	...	...	15
...	...	...	...	...	...	...	...	...	...	...	...	16
...	...	...	...	...	...	...	...	...	...	...	...	17
...	...	...	...	[1]24	...	...	...	...	...	...	...	18
...	...	...	...	[1]72	...	...	...	...	...	...	...	19
...	...	[2]3.7	...	[1]80	...	...	...	...	...	...	...	20
...	...	...	...	[1]20	...	[2]15	...	...	...	...	...	21
...	...	...	...	...	...	...	...	...	...	...	...	22
...	...	[2]0.5	...	...	...	...	...	...	...	...	...	23
...	...	[2]0.5	...	...	...	...	...	...	...	...	...	24
...	...	[2]0.5	...	...	...	...	...	...	...	...	...	25
...	...	[2]3.8	...	...	...	...	...	...	...	...	...	26
...	...	[2]2	...	...	...	...	...	...	...	...	...	27
...	...	[2]3.3	...	...	...	...	...	...	...	...	...	28
...	...	[2]3	...	...	...	...	...	...	...	...	...	29
...	...	...	...	...	[1]0.1	...	...	...	...	...	...	30
...	...	...	...	...	...	[2]6.8	...	...	...	...	...	31
...	...	...	...	...	...	...	...	...	...	...	...	32
...	...	...	...	...	...	...	...	...	...	...	...	33
...	...	...	...	...	...	...	...	...	...	...	...	34
...	...	...	...	...	...	...	...	...	...	...	...	35
...	...	...	...	...	...	...	...	...	...	...	...	36
...	...	...	...	...	...	...	...	...	...	...	...	37
...	...	...	...	...	...	...	...	...	...	...	...	38
...	...	...	...	...	...	...	...	...	...	...	...	39
...	...	...	...	...	...	...	...	...	...	...	...	40
...	...	...	...	...	...	...	...	...	...	...	...	41
...	...	...	...	[1]22	...	...	...	...	...	...	...	42
...	...	...	...	...	...	...	...	...	...	...	...	43
...	...	...	...	...	...	...	...	...	...	...	...	44
...	...	...	...	...	...	...	...	...	...	...	...	45
...	...	...	...	...	...	...	...	...	...	...	...	46
...	...	...	...	...	...	...	...	...	...	...	...	47
...	...	...	...	...	...	...	...	...	...	...	...	48
...	...	...	...	[1]28	...	...	...	...	...	...	...	49
...	...	...	...	...	...	...	...	...	...	...	...	50
...	...	...	...	...	...	...	...	...	...	...	...	51
...	...	[2]2	...	...	...	[2]10	...	...	...	...	...	52
...	...	[2]1	...	...	...	...	[2]5	...	...	...	...	53
...	...	...	...	...	...	[2]20	...	...	...	...	...	54
...	...	...	...	...	...	...	...	...	...	...	...	55
...	...	...	...	...	...	...	...	...	...	...	...	56
...	...	...	...	...	...	...	...	...	...	...	...	57
...	...	[2]1	...	...	...	[2]40	...	...	...	...	...	58
...	...	...	...	...	...	...	...	...	...	...	...	59

TABLE B (PART II).—*Percentage of rarer mineral*

	Locality.	Serial No.	Scientific name.	Common name.	Fluorite.	Microperthite.	Hematite.	Zircon.
60	Quincy, Norfolk County, Mass.	18	Diabase	Trap				
61	Do	299	Diabase (uralitic)	do				
62	Roberts Station, Ga	420	Diabase	do				
63	Rockhill, Pa	731	do	do				
64	Rockland Lake, N. Y	335	do	do				
65	Saugus, Essex County, Mass.	22	do	do				
66	Do	25	do	do				
67	Do	28	do	do				
68	Do	32	do	do				
69	Do	84	do	do				
70	Shadyside, N. J	566	do	do				
71	Somerville, Middlesex County, Mass.	19	Diabase (gabbroitic)	do				
72	Do	75	Diabase	do				
73	Sterling, Worcester County, Mass.	83	do	do				
74	Ware, Hampshire County, Mass.	64	do	do				
75	Westfield, Hampden County Mass.	517	do	do				
76	West Springfield, Hampden County, Mass.	12	do	do				
77	Do	67	do	do				
78	Do	91	do	do				
79	Do	93	do	do				
80	Winchester, Middlesex County, Mass.	59	do	do				
81	Asheville, N. C	628	Diorite	do				[1] 1
82	Beverly, Essex County, Mass.	117	do	do				
83	Campo, Fla	472	do	do				
84	Charlottesville, Va	490	do	do				
85	Delaware River, Pa	352	do	do				
86	Havana, Cuba	575	do	do				
87	Lake City, Colo	409	do	do				[1] 0.1
88	Millville, Worcester County, Mass.	227	do	do				
89	Newbury, Essex County, Mass.	35	do	do				
90	Providence, R. I	659	Augite-diorite	do				
91	Salem, Essex County, Mass.	1	do	do				
92	Do	611	Diorite (vogesite)	do				
93	Watertown, Middlesex County, Mass.	96	Diorite	do				
94	Winchester, Middlesex County, Mass.	56	do	do				
95	Do	304	do	do				
96	Canton, Ga	583	Eclogite	Garnet rock				
97	Glen Mills, Pa	254	do	do				
98	Ashboro, N. C	514	Felsite	Porphyry				
99	Boston, Suffolk County, Mass.	40	do	do				
100	Lynn, Essex County, Mass.	24	do	do				
101	Do	27	do	do			[1] 10	
102	Quincy, Norfolk County, Mass.	72	do	do				
103	Revere, Suffolk County, Mass.	3	do	do				
104	Do	124	do	do				
105	Rowley, Essex County, Mass.	97	do	do				
106	Saugus, Essex County, Mass.	86	do	do				
107	Do	87	do	do				
108	Weymouth, Norfolk County, Mass.	92	do	do				
109	Bergen, N. J	249	Gabbro	Trap				
110	Cortland, N. Y	195	do	do				
111	Lambertsville, N. J	253	Uralite gabbro	do				
112	Do	387	Gabbro	do				
113	Rocky Hill, N. J	248	do	do				
114	Do	285	Uralite gabbro	do				
115	Athol, Worcester County, Mass.	88	Gneiss	Gneiss				[1] 0.1
116	Albemarle County, Va	613	do	do				[1] 0.1
117	Atlanta, Ga	422	Hornblende-gneiss	do				
118	Auburn, Worcester County, Mass.	203	Gneiss	do				

constituents in road-making rocks—Continued.

Allanite.	Rutile.	Limonite.	Glaucophane.	Rock glass.	Tourmaline.	Kaolin.	Scolecite.	Natrolite.	Hypersthene.	Nephelite.	Opal.	
												60
												61
		[2]1.4				[2]3						62
												63
						[2]7						64
												65
												66
												67
												68
												69
							[2]7					70
						[2]14						71
[1]5												72
						[2]0.1						73
												74
						[2]3						75
												76
												77
												78
												79
												80
		[2]0.1										81
						[2]16						82
						[2]2						83
												84
		[2]0.2				[2]10						85
						[2*]57.8		([2*])				86
												87
						[2]1.6						88
												89
						[2]11						90
												91
						[2]1						92
												93
												94
						[2]15						95
												96
												97
												98
												99
												100
												101
												102
												103
		[2]2				[2]0.1						104
												105
												106
												107
												108
		[2]1				[2]6						109
									[1]14			110
						[2]30						111
						[2]18.2						112
						[2]3						113
						[2]35.8						114
						[2]0.1						115
		[2]1										116
												117
		[2]0.1				[2]0.1						118

TABLE B (PART II).—*Percentage of rarer mineral*

	Locality.	Serial No.	Scientific name.	Common name.	Fluorite.	Microperthite.	Hematite.	Zircon.
119	Augusta, Ga	419	Granite-gneiss	Gneiss				[1]0.1
120	Ashby, Middlesex County, Mass.	118	Gneiss	do				
121	Dartmouth, Bristol County, Mass.	77	do	do		([1]*)		
122	Duxbury, Plymouth County, Mass.	5	do	do				
123	Lee, Berkshire County, Mass.	51	Hornblende gneiss	do				
124	Little Falls, N. Y	532	Granite gneiss	do				
125	Marion, Plymouth County, Mass.	13	Gneiss	do				
126	Newburyport, Essex County, Mass.	37	do	do				
127	Occoquan, Va	581	do	do				
128	Round Island, N. Y	100	do	do				([1]*)
129	Toccoa, Ga	468	Granite gneiss	do				[1].1
130	Uxbridge, Worcester County, Mass.	63	Gneiss	do				([1]*)
131	Westport, Bristol County, Mass.	81	do	do			([1]†)	
132	Ashby, Middlesex County, Mass.	60	Granite	Granite				
133	Asheville, N. C	627	do	do				
134	Beverly, Essex County, Mass.	62	Hornblende granite	do				([1]*)
135	Do	74	Granite	do				
136	Do	89	Hornblende granite	do				
137	Clinton, Worcester County, Mass.	242	Gneissoid granite	do				
138	Do	279	Granite	do				[1].1
139	Columbia, S. C	374	do	do				
140	Concord, N. C	747	do	do				
141	Do	436	do	do				[1].5
142	Elberton, Ga	416	do	do				
143	Elm City, N. C	431	do	do				
144	Fitchburg, Worcester County, Mass.	256	do	do				
145	Gloucester, Essex County, Mass.	26	Hornblende granitite	do		[1]10		
146	Hanover, N. H	370	Gneissoid granite	do		[1]10		
147	Lithonia, Ga	421	Granite	do				
148	Los Angeles, Cal	578	do	do				[1].1
149	Northampton, Hampshire County, Mass.	8	Hornblende granitite	do				
150	Orange, Franklin County, Mass.	39	do	do				[1].1
151	Pacolet, S. C	375	Granite	do				
152	Quincy, Norfolk County, Mass.	17	do	do		([1]†)		
153	Rockport, Essex County, Mass.	34	do	do				[1]2
154	Saugus, Essex County, Mass.	15	do	do				
155	Do	32	do	do				
156	Sherman, Colo	397	do	do			[2]1	
157	Taunton, Bristol County, Mass.	445	do	do				
158	Waltham, Middlesex County, Mass.	4	do	do				
159	Wilson, N. C	432	Granitite	do				
160	Do	433	do	do			[2]2	
161	Winchester, Middlesex County, Mass.	57	do	do				
162	Do	58	do	do			([1]*)	
163	Worcester, Worcester County, Mass.	266	do	do	[1]0.2			
164	Cumberland, R. I	14	Peridotite	Trap				
165	Wanaque, N. J	478	Peridotite (Lherzolite)	do				
166	Basic City, Va	493	Quartzite	Quartzite				[1]0.2
167	East Providence, R. I	43	do	do				
168	Do	48	do	do				
169	Great Barrington, Berkshire County, Mass.	80	do	do				[1].1
170	Lee, Berkshire County, Mass.	121	do	do				[1].2
171	Merrimac, Essex County, Mass.	329	do	do				[1].1

constituents in road-making rocks—Continued.

Allanite.	Rutile.	Limonite.	Glaucophane.	Rock glass.	Tourmaline.	Kaolin.	Scolecite.	Natrolite.	Hypersthene.	Nephelite.	Opal.	
....	....	[2]2	....	....	....	....	....	....	....	....	....	119
....	....	....	....	....	....	[2]2.5	....	....	....	....	....	120
....	[1]1	....	....	....	....	....	....	....	....	....	....	121
....	....	....	....	....	....	....	....	....	....	....	....	122
....	....	....	....	....	....	....	....	....	....	....	....	123
....	....	....	....	....	....	....	....	....	....	....	....	124
....	....	....	....	....	....	....	....	....	....	....	....	125
....	....	....	....	....	....	....	....	....	....	....	....	126
....	....	[2]0.1	....	....	....	....	....	....	....	....	....	127
....	....	....	[1]35	....	....	....	....	....	....	....	....	128
....	....	....	....	....	....	....	....	....	....	....	....	129
....	....	....	....	....	....	....	....	....	....	....	....	130
....	....	....	....	....	....	....	....	....	....	....	....	131
....	....	....	....	....	....	[2]1	....	....	....	....	....	132
....	....	[2]2	....	....	....	....	....	....	....	....	....	133
....	....	....	....	....	....	....	....	....	....	....	....	134
....	....	....	....	....	....	....	....	....	....	....	....	135
....	....	....	....	....	....	....	....	....	....	....	....	136
....	....	....	....	....	....	....	....	....	....	....	....	137
....	....	[2]2	....	....	....	....	....	....	....	....	....	138
....	....	....	....	....	....	[2]7	....	....	....	....	....	139
....	....	[2]3.9	....	....	....	....	....	....	....	....	....	140
....	....	....	....	....	....	....	....	....	....	....	....	141
[2].5	....	....	....	....	....	[2]1	....	....	....	....	....	142
....	....	[2]1.5	....	....	....	....	....	....	....	....	....	143
....	....	....	....	....	....	[2]2	....	....	....	....	....	144
....	....	....	....	....	....	....	....	....	....	....	....	145
....	....	....	....	....	....	....	....	....	....	....	....	146
....	....	....	....	....	....	....	....	....	....	....	....	147
....	....	[2].6	....	....	....	[2]2.7	....	....	....	....	....	148
....	....	....	....	....	....	[2]14	....	....	....	....	....	149
....	....	....	....	....	....	....	....	....	....	....	....	150
....	....	....	....	....	....	....	....	....	....	....	....	151
....	....	....	....	....	....	....	....	....	....	....	....	152
....	....	....	....	....	....	....	....	....	....	....	....	153
....	....	....	....	....	....	....	....	....	....	....	....	154
....	....	....	....	....	....	....	....	....	....	....	....	155
....	....	....	....	....	....	....	....	....	....	....	....	156
....	....	[2]1	....	....	....	....	....	....	....	....	....	157
....	....	....	....	....	....	....	....	....	....	....	....	158
....	....	....	....	....	....	[2]15	....	....	....	....	....	159
....	....	....	....	....	....	[2]7	....	....	....	....	....	160
....	....	....	....	....	....	....	....	....	....	....	....	161
....	....	....	....	....	....	....	....	....	....	....	....	162
....	....	....	....	....	....	[2]7	....	....	....	....	....	163
....	....	....	....	....	....	....	....	....	....	....	....	164
....	....	....	....	....	....	....	....	....	[1]40	....	....	165
....	....	[2]1	....	....	....	....	....	....	....	....	....	166
....	....	[2]1	....	....	....	....	....	....	....	....	....	167
....	....	....	....	....	....	....	....	....	....	....	....	168
....	....	....	....	....	....	....	....	....	....	....	....	169
....	....	[2].5	....	....	....	....	....	....	....	....	....	170
....	[1]0.1	....	....	....	....	....	....	....	....	....	....	171

TABLE B (PART II).—*Percentage of rarer mineral*

	Locality.	Serial No.	Scientific name.	Common name.	Fluorite.	Microperthite.	Hematite.	Zircon.
172	Methuen, Essex County, Mass.	181	Quartzite	Quartzite				[1] .1
173	Do	226	do	do				
174	Monticello, Va	499	do	do				
175	Newport, R. I	189	do	do				[1] .1
176	Rowena, S. Dak	449	do	do			[2] 2.6	[1] .1
177	Seattle, Wash	476	do	do				
178	Berlin, Wis	667	Rhyolite	Porphyry				
179	Do	668	do	do				
180	Brookline, Norfolk County, Mass.	368	do	do				
181	Capital City, Colo	399	Rhyolite (breccia)	do			[2] 5	
182	Hinsdale, Colo	398	Rhyolite	do			[2] 5	
183	Lake City, Colo	396	Rhyolite (breccia)	do				
184	Lake Shore, Colo	406	Rhyolite (tuff)	do				
185	Madison, Wis	746	Rhyolite	do				
186	Utley, Wis	695	do	do				[1] .1
187	Do	696	do	do				[1] .2
188	Cumberland, Md	427	Sandstone	Sandstone				
189	Wilkesbarre, Pa	697	do	do				[1] .2
190	Deerpark, N. Y	344	do	do				[1] .1
191	Duanesburg, N. Y	94	do	do				
192	Fort Smith, Ark	742	do	do				[1] .1
193	Do	743	do	do				[1] .1
194	Kentawa, Ky	457	do	do				
195	Milton, Norfolk County, Mass.	196	do	do				[1] .1
196	Stonington, Miss	453	do	do				
197	Vicksburg, Miss	753	do	do				
198	Albemarle County, Va	612	Chlorite schist	Schist				
199	Alexandria County, Va	412	Mica schist	do			[2] .1	
200	Asheville, N. C	469	Hornblende schist	do				
201	Do	705	do	do				
202	Athol, Mass	88	Schist	do				
203	Buckland, Franklin County, Mass.	52	Augite mica schist	do				
204	Charlottesville, Va	491	Chlorite schist	do				
205	Do	496	Hornblende schist	do				
206	Do	497	do	do				
207	Do	498	Biotite schist	do				[1] .1
208	Do	552	Hornblende schist	do				
209	Chester, Hampden County, Mass.	44	do	do				
210	Clinton, Worcester County, Mass.	244	Mica schist	do				.1
211	Goat Island, Wash	508	Chlorite schist	do				
212	Great Barrington, Berkshire County, Mass.	98	Mica schist	do				
213	Hanover, N. H	371	Hornblende schist	do				
214	Lebanon, N. H	372	do	do				
215	Do	373	Biotite schist	do				
216	Lenox, Berkshire County, Mass.	10	Muscovite schist	do				
217	Pittsfield, Berkshire County, Mass.	69	Mica schist	do				
218	Quincy, Norfolk County, Mass.	718	Chlorite schist	do				
219	Rockport, Me	123	Biotite schist	do				
220	Shadwell, Va	500	Chlorite schist	do				
221	Webster, Worcester County, Mass.	411	Muscovite schist	do				
222	Brookline, Norfolk County, Mass.	367	Slate	Slate				
223	Hudson, N. Y	385	do	do				
224	Concord, N. C	513	Syenite	Trap				
225	Gloucester, Essex County, Mass.	30	Augite syenite	do				
226	Milton, Norfolk County, Mass.	218	do	do				
227	Salem, Essex County, Mass.	115	do	do				
228	Waltham, Middlesex County, Mass.	639	Syenite	do				[1] .1
229	California	79	Trachyte	do				
230	Saugus, Essex County, Mass.	90	do	do				

constituents in road-making rocks—Continued.

Allanite.	Rutile.	Limonite.	Glaucophane.	Rock glass.	Tourmaline.	Kaolin.	Scolecite.	Natrolite.	Hypersthene.	Nephelite.	Opal.	
		[2]2.9										172
												173
		[2]4.5										174
		[2].5										175
												176
		[2]8.7				[2]5						177
		[2]1.3										178
		[2]2										179
												180
												181
												182
		[2]3										183
		[2]1				[2]25						184
												185
												186
												187
		[2]11.1			[1]0.1							188
		[2]1.2										189
		[2]4.3										190
		[2]12				[2]20						191
	[1].1	[2].4				[2]4						192
		[2]7				[2]4						193
		[2]4.5										194
		[2]2				[2]3.9						195
		[2]1				[2].5						196
		[2]1									[2]71.3	197
		[2]1										198
												199
												200
		[2].1										201
		[2]5										202
												203
		[2]1.										204
												205
												206
												207
		[2].5										208
		[2].1										209
												210
		[2]1										211
												212
												213
												214
												215
												216
												217
												218
												219
												220
		[2].2										221
												222
												223
						[2]5						224
										[1]1		225
						[2]1						226
						[2]1						227
		[2]1										228
												229
												230

FORMS FOR REPORTING RESULTS OF TESTS, ETC.

INSTRUCTIONS FOR SELECTING AND SHIPPING SAMPLES.

In order to have road materials tested in the laboratory of the Department of Agriculture, the instructions below must be carefully followed:

1. All samples should be selected to represent as nearly as possible an average of the material.

2. A sample of rock for laboratory test must consist of stones which will pass through a 3-inch but not through an inch and a half ring—excepting one piece, which should measure, approximately, 4 by 6 inches on one face and be about 3 inches thick. The whole sample should weigh not less than 30 pounds. It is desired that samples of rock be shipped in burlap bags.

3. A sample of gravel must weigh not less than 25 pounds, and should not contain stones over 1 inch in diameter. Such samples must be shipped in boxes, sufficiently tight to prevent the finer material from sifting out.

4. A sample of paving brick must contain 36 whole bricks, or 24 blocks, which must be securely packed in a box for shipment.

5. A blank form and addressed tag envelope will be supplied by the Department for each sample. The blank form must be filled and placed in the tag envelope, which must be used as the address for the sample. It is essential that these blank forms be filled with the utmost care, as they are filed as records of the samples.

6. The Agricultural Department desires to keep a record of the actual wear on roads built of the materials tested. If the material which this sample represents has been, or is about to be, used on roads, this laboratory desires to be informed of the addresses of those in charge of the construction and maintenance of such roads.

7. Samples must be shipped, freight or expressage prepaid, and bills of lading or express receipts forwarded by mail to the Road Material Laboratory, Bureau of Chemistry, U. S. Department of Agriculture, Washington, D. C.

SHIPPING BLANK.

1. The sample about to be shipped is from the State of ———. County ———. Town or city ———.
2. It comes from the property of ———.
3. If rock, about how many cubic yards are available? ———.
4. Name and address of person sending sample: ———.
5. Date of shipment: ———, 19—.
6. Is test desired by a private person, municipality, or company? ———.
7. Name of person, municipality, or company: ———.
8. Is material intended for general sale to the public? ———.
9. Has material been used on roads? If so, where? ———.

If a judgment of sample's fitness for a particular road is desired, further details must be given, and Form No. 3 will be mailed to you for this purpose.

DO NOT WRITE BELOW THIS LINE.

Date received at laboratory: ———, 19—. Sample No. ——.

Tests made on sample: ———. Abrasion No. ——. Result: ———. Cementation No. ——. Result: ———. Toughness No. ——. Result: ———. Hardness No. ——. Result: ———. Density No. ——. Result: ———.

Name of material: ———.

Other tests: ———.

Condition of sample: ———.

REMARKS: ———.

REPORT ON PHYSICAL TESTS.

Report on sample No. —— of road material from ———.
Made at the request of ———.
Material: ———.

Results of physical tests on sample submitted, and a comparison with highest and lowest results obtained on material of a similar nature.

Determinations.	Results on sample submitted.	Results on similar materials.	
		Highest.	Lowest.
Specific gravity			
Weight per cubic foot	lbs.	lbs.	lbs.
Water absorbed per cubic foot	lbs.	lbs.	lbs.
Per cent of wear			
Hardness			
Toughness			
Cementing value			

An explanation of tests is given in the accompanying circular.
REMARKS:

REPORT ON CHEMICAL AND MINERAL COMPOSITION.

Chemical and mineral composition of sample No. ——— of road material from ———.
Made at the request of ———.
Character of material: ———.

Name:

Essential minerals:

Accessory minerals:

Secondary minerals:

CHEMICAL ANALYSIS:

Silica (SiO_2)	
Alumina (Al_2O_3)	
Iron oxid (Fe_2O_3)	
Manganese oxid (MnO_2)	
Titanium oxid (TiO_2)	
Lime (CaO)	
Magnesia (MgO)	
Alkalies K_2O	
Alkalies Na_2O	
Loss on ignition	
Insoluble in HCl	
Water at 105° C	
Water above 105° C	
Total	

REMARKS:

Date: ———.

ABRASION TEST.

Data.	Material used in test.	Sizes of material after test.				
Inches .... Centimeters...........	2.4–1.2 6–3	2.4–1.2 6–3	1.2–$\frac{1}{16}$ 3–.16	$\frac{1}{16}$–$\frac{1}{100}$ .16–.025	All under $\frac{1}{16}$.	All detritus.
Weight in ounces.....						
Weight in grams......						
Number of pieces.....						
Per cent..............						

Serial No. ———. Name of material ———.
Locality ———.
Date of test ———. Department's coefficient of wear ———.
Made by ———. French coefficient of wear ———.
Percentage of wear ———.
REMARKS:

RATTLER TEST OF PAVING BRICK.

GENERAL REPORT.

Report of Rattler tests on sample No. ——— of paving brick from ———.
Made at request of ———.
Trade name of brick ———.
Condition of sample ———.

Determinations.	Average of charge.		Greatest individual loss.	Least individual loss.
	Test No. 1.	Test No. 2.		
Loss in per cent at ——— revolutions..........	....	....	....	....
Loss in per cent from 1,200–1,800 revolutions ..	....	....	....	....
Loss in per cent at 1,800 revolutions...........	....	....	....	....

Average loss at 1,800 revolutions, in per cent ———.
Highest and lowest results obtained up to the present date on other paving brick ———.
Rattler loss in per cent at —— revolutions ———. Average of charge ———.
Rattler loss in per cent from 1,200–1,800 revolutions ——. " " ———.
Rattler loss in per cent at 1,800 revolutions ———. " " ———.

REMARKS:

Date ———.

DETAILED REPORT.

Serial No. ———. Trade name of brick ———.
Shipped from ———.
Date of test ———. Made by ———.
Condition of sample when received ———.
Size of Rattler ———. Speed of Rattler ——— R. P. M.
Charge ———. Shot ———.
Brick ———.
Size of brick ———.

RESULTS.

Number of brick.	Original weight, kgs.	Loss in Rattler.					
		—— rev.		1,200 rev.		1,800 rev.	
		In kgs.	In percent.	In kgs.	In percent.	In kgs.	In percent.
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
Average							
Greatest							
Least							

REMARKS:

FOR RECORDING VOLUME AND CHARACTER OF TRAFFIC.

N. B.—This form should be used for recording the traffic of one road only.

Each variety of traffic enumerated below should be kept on separate slips of paper and the total number of each variety placed in its proper square after a record of twenty-four consecutive hours has been kept. Less than a week's record is unsatisfactory, and it is best that a record should cover as many seasons of the year as possible. Additional forms will be supplied on application.

1	Loaded one-horse wagon														
2	Unloaded one-horse wagon														
3	Loaded two-horse wagon														
4	Unloaded two-horse wagon														
5	Loaded four-horse wagon														
6	Unloaded four-horse wagon														
7	One-horse pleasure vehicle														
8	Two-horse pleasure vehicle														
9	Rubber-tired vehicle														
10	Unharnessed horse or shod ox														
11	Excessively heavy vehicle[a]														
12	Year														
13	Day														
14	Month.														

[a] 11 is intended for very heavy vehicles such as carry ore, stone, brick, timber, etc.

Traffic on road in State of ———, county ———, town ———.

Name of road, or between what two points was record taken ———.

FIG. 1.—BASALT (TRAP).

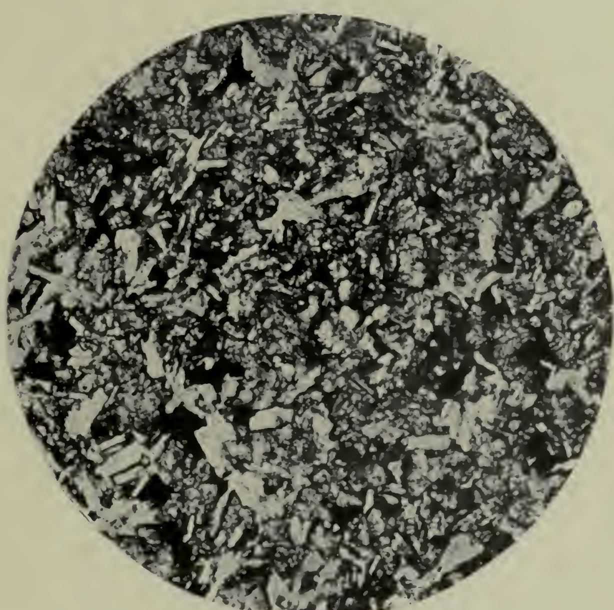

FIG. 2.—DIABASE (TRAP).

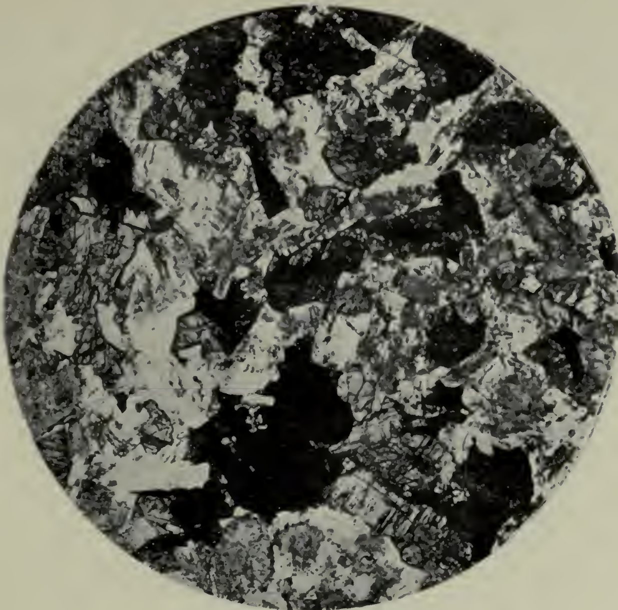

FIG. 1.—GABBRO.

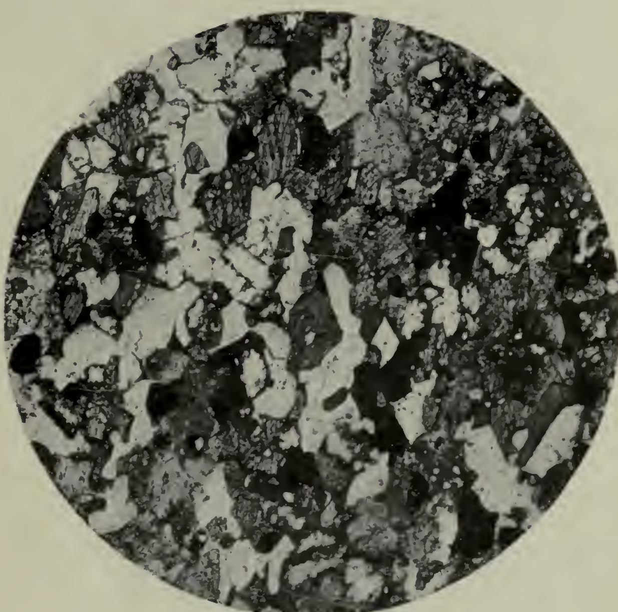

FIG. 2.—DIORITE.

FIG. 1.—GNEISS.

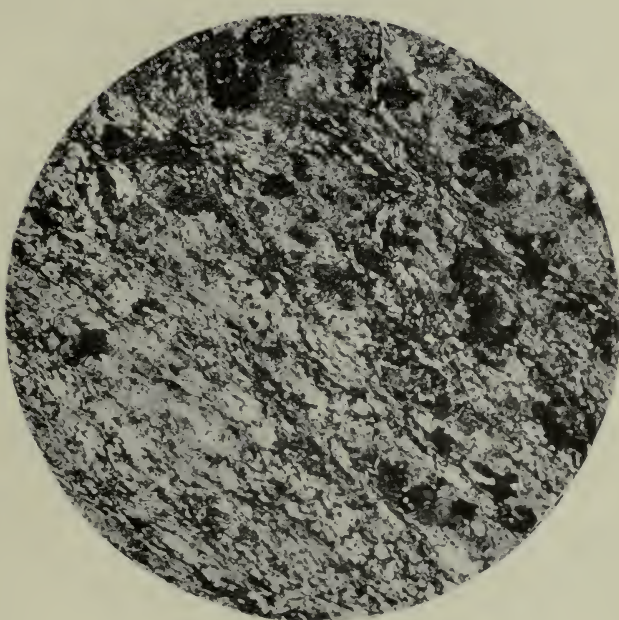

FIG. 2.—MICA-SCHIST.

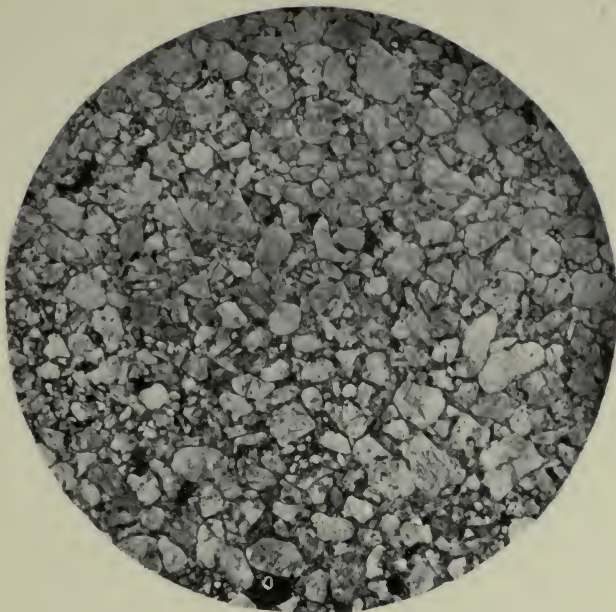

FIG. 1.—QUARTZITE.

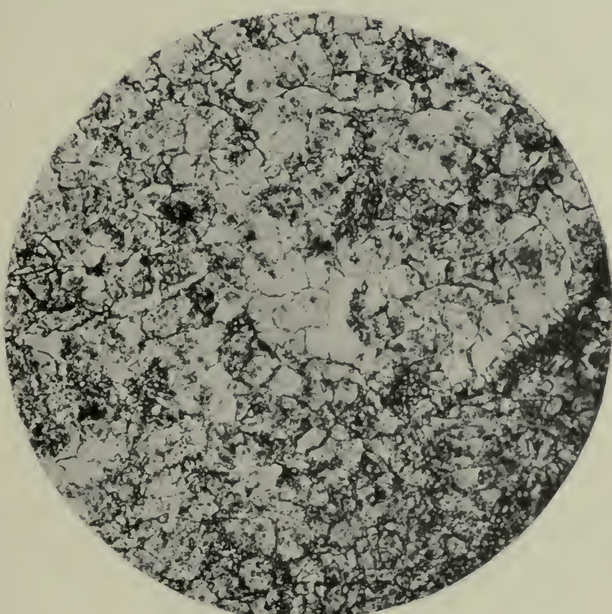

FIG. 2.—LIMESTONE.

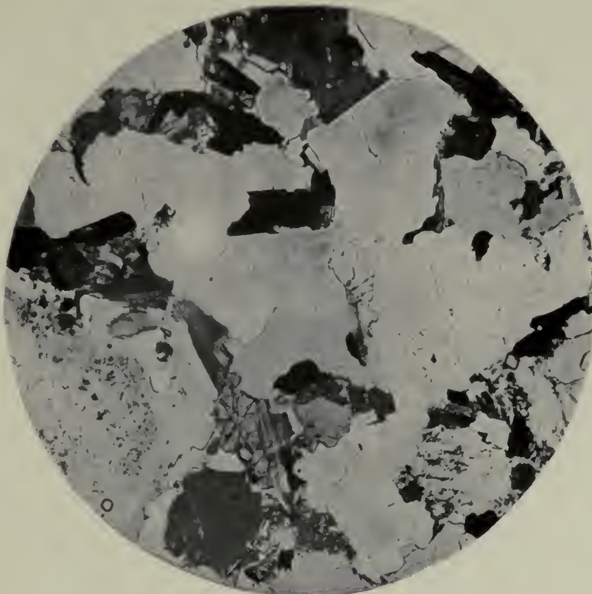

FIG. 1.—GRANITE.

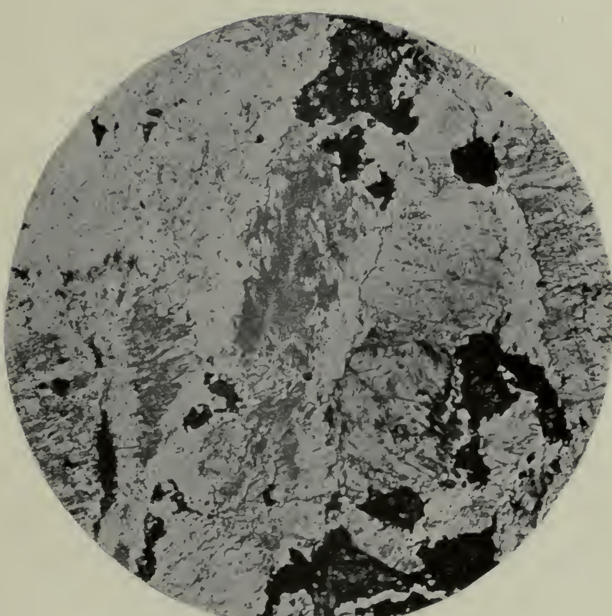

FIG. 2.—SYENITE.